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THE BIOELECTROMAGNETICS SOCIETY

TWELFTH ANNUAL MEETING 1990

ABSTRACTS

Presented at:

Marriott Riverwalk
San Antonio, Texas
June 10-14, 1990

SESSION A-1:	SYMPOSIUM 1 - ISSUES AND MECHANISMS
Organizer:	Stephen Cleary

A-1-1 **NEUROLOGICAL EFFECTS OF LOW-LEVEL MICROWAVE IRRADIATION.** Henry Lai. Department of Pharmacology and the Center for Bioengineering, University of Washington, Seattle, WA 98195.

Research in our laboratory shows that low-level microwave irradiation affects the functions of the central nervous system in the rat. The effects include changes in activity of the central cholinergic systems, alterations in neurotransmitter receptor properties, impairment of spatial memory function, and actions of various psychoactive drugs. Endogenous opioids seem to play a mediating role in most of these effects. We speculate that low-level microwave irradiation is a "stressor" and activation of endogenous opioids in the brain is a part of the stress response.

A-1-2 **CELLULAR EFFECTS OF ELECTROMAGNETIC FIELDS: NONTHERMAL INTERACTION MECHANISMS.** Stephen F. Cleary. Physiology Department, Virginia Commonwealth University Richmond, VA 23298.

Recent studies indicate direct effects of high frequency electromagnetic radiation on living systems, not attributable to induced heating. The most convincing evidence derives from in vitro cellular studies conducted under isothermal exposure conditions. In addition to intensity, effects depend upon exposure duration, sampling time, field modulation, temperature, and other factors. The implication of these findings will be discussed with respect to interaction mechanisms and in vivo effects.

A-1-3 **FREQUENCY AND INTENSITY DEPENDENT INFLUENCE OF MILLIMETER WAVES ON YEAST GROWTH.** W. Grundler. Institute fur Biophysikalische Strahlenforschung, Gesellschaft fur Strahlen-und Umweltforschung mbH, 8042 Neuherberg, F.R.G.

To test the biological effectiveness of weak electromagnetic fields, investigations must be performed using high accuracy in physical parameters, especially of frequency and intensity. This observation has been shown in a number of reports. In our experiments we have controlled some of the physical parameters by using a new, precision irradiation chamber which has a fixed, well-defined intensity distribution that extends over 9 decades. Irradiation experiments with single yeast cells microscopically observed for two generations have generated the following results: 1.) cell growth rate depends on frequency and can vary either as increases or decreases of 10% to 20%, 2.) new data from one resonance peak previously reported using another observation method (frequencies around 41652 MHz)

display the same resonance peak and bandwidth, 3.) the shape of the resonance curve can be changed by the use of radiation of different intensities. These observations, along with those of others also showing non-linear response, may be explained in a general sense by the theory of non-linear dynamics. As a hypothesis to adapt this theory to our results, we must conclude that only non-linear self-sustained oscillators can respond in the way we have experimentally observed. If this hypothesis is true, then in our yeast system there may be an active, internal "oscillator" that is normally coupled to cell growth in an unknown manner, but which is interfered with by the external electromagnetic field.

A-1-4 **INTERACTION OF MODULATED ELECTROMAGNETIC RADIATION WITH BIOLOGICAL SYSTEMS: THEORETICAL PREDICTIONS AND EXPERIMENTAL DATA.** V.V. Lednev. Institute for Biological Physics, Scientific Center for Biological Research, Academy of Sciences, Puschino, USSR.

A physical mechanism is suggested for resonance interaction of weak magnetic fields with biological systems. An ion inside Ca^{2+} binding proteins or within a hydrated shell is approximated by a charged spatial oscillator. A shift appears between energetically different types of interaction of the ion with the surrounding molecules when a combination of stationary and alternating magnetic fields is applied. The effect reaches its maximum when the frequency of the alternating field is formally equal to the cyclotron frequency for this ion, or to some of its higher harmonics. A resonance response of the biosystem to the magnetic field results. The proposed theory permits a quantitative explanation for the main characteristics of experimentally observed effects.

A-1-5 **WEAK ELECTROMAGNETIC FIELD EFFECTS: POSSIBLE INTERACTION MECHANISMS.** James C. Weaver and Alan Barnett. Harvard-MIT Division of Health Sciences and Technology, Massachusetts Institute of Technology, Cambridge, MA 02139; R. Dean Astumian, Center for Chemical Technology, National Institute of Standards and Technology, Gaithersburg, MD 20899.

Epidemiological, in vivo and in vitro studies support the view that weak electromagnetic fields may interact with biological systems, but the basic mechanism of interaction remains unknown. Magnetic fields can penetrate tissue and cause electric fields. We assume that direct magnetic interaction with cells is weak, and focus on electric fields. We further assume that the site of interaction is the cell membrane. To estimate thresholds we consider the external electric field to be a "signal" which must compete with noise in the cell membrane. If the signal-to-noise ratio exceeds unity, a response could occur. Candidate types of noise include thermal noise ("kT noise"), 1/f noise and noise associated with fluctuating opening and closing of channels. Candidate membrane interactions include: (1) pre-existing channels, (2) electroconformation of membrane macromolecules, and (3) sponta-

neously created pores. In all cases a change in the external electric field causes changes in the transmembrane potential, U(t), which changes the intense electric field within the membrane, E_m. As a result, pre-existing channels may change their conformation and their transport. Electroconformation of membrane-associated enzymes may result in altered catalyzed reaction rates. The possibility of rate subpopulation effects (only a small number of responding cells) may be a fundamental attribute of spontaneous pores. We will consider some of these possibilities, and discuss some implications for designing experimental studies.

SESSION A-2:	**POSTERS & DISCUSSION 1-EPIDEMIOLOGY**
Moderators:	Dana Loomis, Gierri Lee and Nancy Wertheimer

A-2-1 **ASSESSMENT OF ALTERNATIVE METHODS FOR CLASSIFICATION OF CHILDREN'S EXPOSURE TO MAGNETIC FIELDS.** Michael D. Koontz* and Niren L. Nagda*. GEOMET Technologies, Inc., Germantown, MD 20874. Fred M. Dietrich*, Electric Research & Management, Inc., Pittsburgh, PA 15238.

This pilot study is intended to assess the level of measurement or observational detail required to provide reasonably accurate predictions or classifications of children's 24-hour exposure to magnetic fields. Study subjects are being chosen from randomly selected census blocks in a geographic area near Washington, D.C. Subjects in two age groups (under 4 years old and 8 to 11 years old) are being recruited from randomly selected households in these blocks, guided by a screening survey to characterize their general location/activity patterns. Older children will be personally monitored with an EMDEX meter worn at waist level and will complete location/activity cards each time they change environments. Younger children will carry a smaller three-axis AMEX meter at waist level; parents/guardians of these children will place an EMDEX meter in the general area occupied by the child and complete location/activity cards on the child's behalf. Predictive tools for classifying children's total exposure will be developed from stationary measurements in certain environments collected in parallel with personal monitoring and from spot measurements and observations inside/outside children's residences and other environments where children spend the largest blocks of time. Measurements are to be obtained during the winter and summer of 1990. The results to be presented at the meeting, based on the winter measurements, will focus on the contributions or different environments to children's total exposure and the ability of predictive tools with varying degrees of measurement sophistication to correctly classify children's total exposure. This work is supported by the Electric Power Research Institute, RP2966-4.

A-2-2 **A STUDY ON THE RELATIONSHIP BETWEEN THE EXPOSURE DOSE OF ULTRA SHORT WAVE AND DECREASED WBC COUNT OF THE WORKERS BY CURRENT LIFE TABLE.** Zongqun Zhao, and Shuzhen Zhang. Dept. of Occup. Health, Beijing Medical University, Beijing 100083, China.

92 workers whose length of service was over one year were exposed to ultra short wave (30-300 MHz) at 30 v/m. They were divided into 10 groups according to exposure level (v/m x working year). The result by current life table showed that 50% of 92 workers might have maximum work life for 22 years when 4000/cm^3 of WBC count was taken as upper limit.

A-2-3 **RESIDENTIAL EXPOSURES TO MAGNETIC AND ELECTRIC FIELDS IN THE LOS ANGELES CHILDHOOD LEUKEMIA STUDY.** J.D. Bowman[1], J.M. Peters[1], S.J. London[1], D.C. Thomas[1], E. Sobel[1], L.J. Wang[2], and K. Holte[3]. Departments of [1]Preventive Medicine and [2]Electrical Engineering, University of Southern California, Los Angeles, CA; [3]Southern California Edison, Irwindale, CA.

The exposure assessment in the Los Angeles County childhood leukemia study consisted of measurements of the residential fields, mapping of wire configurations, and exterior measurements of electric current in distribution lines and water pipes. The interior measurements consisted of 24-72 hour magnetic field dosimetry, spot measurements of ELF electric and magnetic fields at normal and low power, and a flux gate magnetometer measurement of the static magnetic field. For residences where access was denied, we measured the magnetic field over the water pipe and recorded currents in neighboring distribution lines for 24-72 hours with Load Loggers. For all residences for which we had a complete address, we measured the wiring configurations and obtained utility maps of the distribution lines. The exposure data was analyzed with statistical and physical models to estimate residential magnetic fields. Where interior measurements were not taken, the residential magnetic fields are calculated with the Biot-Savart Law, using the load logger current measurements, assumptions on the current phases in the distribution lines, and distances between the line and the house. From the wiring maps, 40 wiring configuration parameters have been coded for a regression analysis against the measured magnetic fields. The Wertheimer-Leeper classifications for wiring configurations are also derived from the maps. From these measurements and models, exposure estimates are derived for the epidemiological analysis.

This research is supported by the Electric Power Research Institute.

A-2-4 **CHILDHOOD LEUKEMIA AND RESIDENTIAL ELECTRO-MAGNETIC FIELDS.** J.M. Peters, J.D. Bowman, E. Sobel, D.C. Thomas, and S.J. London. Division of Occupational and Environmental Medicine, Department of Preventive Medicine, University of Southern California, Los Angeles, CA.

The objective of the study is to test the hypothesis that exposures to ELF magnetic and/or electric fields increase risk of childhood leukemia. Cases are 232 children up to 10 years of age who live in Los Angeles County and were diagnosed with acute leukemia between 1980-1987. 232 controls are matched to each case on age, race and sex. The matched pairs were interviewed by telephone covering residential history, medical history, occupational histories for the parents, electrical appliance usage, and exposure to chemicals in the home. Exposures to magnetic and electric fields were determined by measurements taken within the home where the child lived the longest. The ELF fields were measured with a Denometer at locations inside and outside the home. The ELF magnetic field was recorded for 24-72 hours in the child's bedroom with an EMDEX or IREQ dosimeter. The static magnetic field is measured with a flux gate magnetometer. To estimate exposures in residences where the fields could not be measured, we modeled residential magnetic fields as a function of wiring configurations and building type. Maps of the distribution nd transmission wiring were drawn at 800 subject residences in the Los Angeles area. From these maps 41 wiring configuration parameters are coded on a computerized mapping system. In addition we measured line currents with load loggers and the magnetic field over the residence's water pipe. In 48 residences, the load logging has been done at the same time as the magnetic field dosimetry. The results will be presented.

A-2-5 **ASSESSMENT OF MAGNETIC AND ELECTRIC FIELD EXPOSURE BY JOB CATEGORY.** S.J. London, J.D. Bowman, E. Sobel, and J.M. Peters. Division of Occupational and Environmental Medicine, Department of Preventive Medicine, University of Southern California, Los Angeles, CA.

The purpose of this study was to determine if "electrical" workers have more exposure to electric or magnetic fields than non-electrical workers. Leukemia among "electrical workers" could be due chemicals or ionizing radiation. The "electrical workers" in the study belong to 10-12 job categories which had been used in previous studies of leukemia in three regions. The comparison job categories were sampled randomly from the region's tumor registry. ELF magnetic and electric fields were measured with EMDEX dosimeters worn by the workers. Static magnetic fields and the frequency spectrum of the ELF magnetic fields were also measured. Panels of experienced workers and management to assess present and past exposures to chemicals and to estimate the time spent at different tasks. In New Zealand, we monitored 130 people in 10 "electrical worker" categories and 33 people in 12 comparison categories. The time-weighted average (TWA) magnetic

field exposures had a category mean of 10.4 mG for the "electrical workers" and 1.9 mG for the comparison categories, a difference significant with $p < 0.01$. The odds ratio for leukemia risk is elevated in all electrical workers. With the individual job categories, no dose-response relationship is seen. The welder category which has the highest magnetic field exposure showed no risk. Results of the data collected in Los Angeles County and Washington State will be presented and, if appropriate, combined with the New Zealand data for estimates of leukemia risk by exposure level.

This research supported by the Electric Power Research Institute.

A-2-6 **A LONGITUDINAL STUDY OF A COHORT WITH PAST EXPOSURE TO RADAR: THE MIT RADIATION LABORATORY FOLLOW-UP STUDY.** Doreen Hill. Environmental Protection Agency, Washington, D.C. 20460.

Using a cohort study design, the long-term health effects among participants in a radar research and development project in the Radiation Laboratory (Rad Lab) at the Massachusetts Institute of Technology (MIT) during World War II were examined. The study population included all professional staff members of the MIT Rad Lab, largely consisted of scientists and engineers. Analyses were restricted to white males. After extensive tracing and follow-up, the overall mortality experience, mortality from specific causes of death, and longevity in the cohort were examined. Of the total population of 1592 persons, less than five percent were not traced beyond the 1940's. The majority were followed into the 1980's with an average survival of 36 years. Standardized mortality ratios (SMRs) were calculated and demonstrated a lower than expected mortality based on rates of U.S. white males. A very strong healthy worker effect was evidenced. Certain underlying causes of death were elevated, e.g., Hodgkin's Disease, but none were statistically significant. The population was also compared to a cohort of physicians. The overall survival of the Rad Lab cohort was better than survival among physicians. With the exception of a slightly increased risk of Hodgkins's Disease and cirrhosis of the liver in the Rad Lab population,the cohorts were generally similar with respect to specific causes of death. For internal comparisons, a slight gradient in excess mortality was observed between the group with medium exposure and the group with the highest exposures.

A-2-7 **MAGNETIC FIELD EXPOSURE MISCLASSIFICATION ASSOCIATED WITH VARIOUS SPOT MEASUREMENT PROTOCOLS.** Vincent Delpizzo* Australian Radiation Laboratory, Yallambie, 3085; Michael R. Salzberg* and Steven J. Farish*, Monash Medical School, Praharan 3181, Australia.

We argue that a relatively small number of "spot" measurements may be an adequate alternative to the use of stationary automated magnetic field monitors, which have several disadvantages. To estimate the degree of misclassification of various "spot" measurement protocols we collected 24 hour measurements of the magnetic field in one location in each of 40 houses. Our first analyses focus on a simple dichotomous classification using a cut-off of 0.75 mG. The true magnetic field was defined in two ways in separate analyses: i) the mean 24-h magnetic field, and ii) the mean magnetic field measured between 5:00 pm and 9:00 am (these may be the hours when most residential exposure occurs). Using these 24-hour data we simulated various protocols. We used a random procedure to select subsets of readings at various times of the day and determined the rate of misclassification of each protocol. We found that a single spot measurement had at least an 80% chance of classifying houses correctly and that this probability did not increase significantly as the number of readings was increased. We also calculated the sensitivity and specificity of each protocol and, from these, the effect of the observed degree of misclassification of estimates of relative risk. Future analyses will extend to ordinal exposure scales. Since relatively large spatial variations in background magnetic field may be encountered in homes, we suggest that a small number of readings collected manually in several points within a residence may characterize the magnetic field better than continuous monitoring at one fixed location.

SESSION A-3: **POSTERS & DISCUSSION 2- CANCER**
Moderators: Craig Byus, Martin Meltz and Jerry Phillips

A-3-1 **EMF AND CANCER: HYPOTHETICAL MECHANISMS LINKING EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS AND CANCER.** Robert B. Goldberg and William A. Creasey* Information Ventures, Inc., 1500 Locust St., Suite 3216, Philadelphia, PA 19102.

A body of epidemiological evidence suggests an association between residential or occupational exposure to extremely low frequency (ELF) electromagnetic fields (EMF) and an increased incidence of cancer in children and adults. Experimental studies at the whole-animal and cellular level are ambiguous: bioeffects suggestive of a carcinogenic effect have been reported, but a similar volume of negative reports can also be assembled. This literature was critically reviewed in our previous EPRI Report, EMF and Cancer (Creasey and Goldberg, 1989). We are now reviewing the

literature based on the hypothesis that the epidemiological results are correct, and asking what plausible mechanism could explain a small increase in the incidence of a range of tumors with a nonspecific increased exposure to ELF EMF? It is possible to construct many hypothetical mechanisms that amount to little more than ungrounded speculation: we have tried to avoid this by focusing on four likely mechanisms, discussing the evidence supporting them, and suggesting specific experiments likely to be productive in resolving their relevance to putative EMF hazards. The four hypothetical mechanisms are: (1) disruption of cell communication by a promoter-like action on cell membranes; (2) activation of specific gene sequences involved in a cancer cell phenotype; (3) disruption of normal hormonal control, especially nocturnal pineal melatonin peaks which may suppress tumor growth; and (4) disruption of immunosurveillance. Evidence for these mechanisms will be discussed in the broader context of cancer research. Sponsored by the Electric Power Research Institute under Technical Agreement Number RS1965-12.

A-3-2 **EFFECT OF A 9 mT 460 Hz PULSED MAGNETIC FIELD ON C3H/Bi TUMORAL FEMALE MICE.** Andre Bellossi* and Andree Desplaces**. *Laboratoire de Biophysique, Faculte de Medecine, Av. du Pr. Leon Bernard, 35043 Rennes Cedex France. **Centre Rene Huguenin, St Cloud France.

C3H/Bi female mice develop spontaneous viral induced mammary carcinoma which give metastases to the lungs. In a previous experiment the exposure 10 min a day 3 times a week to a 6 mT 460 Hz pulsed magnetic field (PMF) delivered through a Magnobiopulse apparatus (Societe ATLAS, Paris, France) had not changed the survival time. However at death time, the tumors and the spleens were less heavy and there were less abnormal heavy lungs in the exposed mice than in the controls. In the present experiment the field strength was 9 mT. Fifty mice were used as controls, while 47 mice were exposed. Though the actuarial survival curves were in favor of the exposed mice, the mean survival times were not statistically different in the two groups. However the histograms were different. The histogram of the controls remained unimodal whereas in the histogram of the exposed mice two subpopulations appeared on both sides of the interval 34-41 days as if death had been promoted for some mice (21%), and delayed for the other ones. Besides, at death time the exposed mice's spleens were significantly heavier than the controls' ones and there was no difference between the tumor weights of the two groups. In the exposed group there were also less abnormal heavy lungs than in the control one.

A-3-3 **LYMPHATIC LEUKEMIA IN MICE EXPOSED TO 60 HZ MAGNETIC FIELDS.** T. Makinodan*, W.J. Peterson*, M. Nasu*, S.G. Mirell* and H. Niewisch*. GRECC, VA Med. Ctr. West Los Angeles and Dept. of Medicine, UCLA, Los Angeles, CA 90073 (Sponsor: Charles N. Rafferty, EPRI, Palo Alto, CA).

The purpose of this study is to evaluate the carcinogenicity of 60 Hz magnetic fields in C57BL/6 mice chronically exposed to magnetic fields. The experiments are designed to determine whether 60 Hz magnetic fields can act as a complete carcinogen, a co-carcinogen, or as a promoter, using ionizing radiation as the primary carcinogen. The experiments will be conducted over the natural life span of the animals or until the disease endpoints are fully developed. The magnetic fields will be circularly polarized to insure a more uniform induced currents; three levels of intensities will be employed [<1 milligauss (sham), 0.1 gauss and 10 gauss] to simulate the values found in diverse residential and occupational environments; and the animals will be continuously exposed for 20 hours per day. Biological assays will be performed on animals to detect pathological changes associated with lymphatic leukemia and to monitor the general health and physiological status of the animals. Standard rodent necropsies will be performed on all moribund and dead mice, provided their tissues have not autolyzed extensively, and all organs and tissues will be stored in appropriate fixatives. The statistical design of the study should allow for the detection of a doubling of the incidence of lymphatic leukemia in the groups used to test for promotional or co-carcinogenic effects of magnetic fields with a power of 0.90. Supported by EPRI RP 2965-11.

A-3-4 **EFFECT OF 60-Hz ELECTROMAGNETIC FIELDS ON GROWTH RATES AND TRANSFORMATION FREQUENCIES OF $C_3H10T1/2$ CELLS.** Marvin E, Frazier, Judith A. Reese* and James E. Morris. Pacific Northwest Laboratory, P.0. Box 999, Richland, WA 99352.

Interactions of electromagnetic fields (EF) and cultured cells with respect to growth and cell transformation rates are being examined in an effort to formulate mechanisms by which such exposures could result in increased cancer incidence in humans. $C_3H10T1/2$ were chosen as the indicator cells. Results indicate that exposure to electric fields (≤10 V/m) or magnetic fields (≤6 gauss) alone or in combination do not alter population doubling times. In the in vitro correlate to initiation-promotion, $C_3H10T_1/2$ cells first receive an initiating dose of radiation with the promoter, 12-0-tetradecanoyl-phorbol-13-acetate (TPA), added 24 hours after irradiation and at weekly intervals thereafter. The TPA treatment caused an approximately a 10-fold increase in the transformation frequencies of initiated (irradiated) cultures compared with transformation frequencies in irradiated but unpromoted cultures. 60-Hz ac magnetic fields of 0.1, 0.75, or 6.0 gauss did not significantly alter transformation frequencies (TF) of $C_3H10T_1/2$ cells (relative to

background) nor did they enhance TF of radiation initiated cultures. Studies underway are examining the ability of 60-Hz ac electric fields and combined 60-Hz ac electric plus magnetic fields to transform and/or promote transformation. Work supported by the U.S. Department of Energy/Office of Energy Storage and Distribution under contract #DE-AC06-76 RLO-1830.

A-3-5 **TUMOR PROMOTION IN THE MOUSE SKIN BY 60 HZ MAGNETIC FIELD.** Jack McLean, Maria A. Stuchly, Ronald Mitchel[1], Diana Wilkinson and David W. Lecuyer. Bureau of Radiation and Medical Devices, 775 Brookfield Road, Ottawa, Ontario, K1A 1C1. [1]Atomic Energy of Canada, Ltd.

The motivation for this study was provided by epidemiological studies indicating increased rates of cancer in people likely exposed to 60 Hz magnetic and/or electromagnetic fields. Promotion and co-promotion were investigated because of the results of in-vitro studies. The mouse skin model was selected because of its versatility for manipulation, relatively short duration of exposures required, and a large data base available. Four groups, 32 animals each, of Sencar mice were initiated at a subthreshold dose with a known chemical carcinogen (DMBA). Two groups, to study promotion, were sham or field exposed to a magnetic flux density of 2 mT, for 6h/day, 5 days/week for 21 weeks. Two other groups, to study co-promotion, were treated weekly with a known tumor promoter (TPA), and sham or field exposed. Papillomas were scored weekly and evaluated histopathologically at the end of the experiment. Natural killer (NK) cell activities in blood and spleen were also assayed. No tumors or differences in the NK activity were found in the promotion groups. An earlier, but not statistically significant, onset of tumors was found in the field exposed group treated with TPA. Also, differences were observed in the NK assay results and the spleen appearance in the co-promotion groups.

A-3-6 **EXTREMELY-LOW-FREQUENCY (ELF) AMPLITUDE MODULATION MEASUREMENTS FOR SELECTED ENVIRONMENTAL RADIOFREQUENCY (RF) SOURCES.** Edwin D. Mantiply. U.S. EPA, Office of Radiation Programs, Las Vegas, NV 89193-8517.

ELF amplitude modulation may be an important variable in evaluating the risk of RF exposure. Because of this concern, modulation was included in an RF exposure criteria document of 1986 developed by the National Council on Radiation Protection and Measurement [NCRP Report No. 86] as follows: "If the (amplitude of the) carrier frequency is modulated at a depth of 50 percent or greater at frequencies between 3 and 100 Hz, the exposure criteria for the general population shall also apply to occupational exposures". The Environmental Protection Agency (EPA) has assembled a measurement system which can be used to implement this criteria. This system is described in an EPA report: Radiofrequency Radiation Survey in the McFarland, California Area, EPA/520/6-89/022. The system determines the amplitude modulation spectrum and total percentage of modulation

between 3 and 100 Hz. This system was applied to a number of environmental RF sources and the results are presented in the poster session. The system had to be reconfigured for measurements near microwave ovens because of the wide bandwidth (greater than 3 MHz) of these sources. RF sources examined which exceed the 50% criteria include amateur keyed-carrier (CW) transmissions and microwave ovens. Common broadcast sources including AM and FM radio and television as well as common air traffic radars have ELF modulation levels of less than 50%. Of these, the highest levels are seen for TV video signals which have ELF modulation levels which vary from about 10 to 20% depending on programming.

A-3-7 **QUANTITATIVE CHANGES IN TRANSCRIPTS RESULT FROM VARYING SIGNAL AMPLITUDE.** Reba Goodman, L-X Wei, J-C Xu, and Ann Henderson. Department of Pathology, Columbia University Health Sciences and Department of Biological Sciences, Hunter College-CUNY, New York, N.Y.

The effect of varying extremely low frequency (elf) electromagnetic fields (EMFs) on the level of specific transcripts in human HL60 cells was measured. Sinusoidal signals with frequencies of 60 and 72 Hz were tested with amplitudes which were increased from 0.5uV to 500uV in log increments [at 5uV, $dB/dT = 3 \times 10^{-3}$ T/sec and $E = 3 \times 10^{-4}$ V/m]. Transcripts with homology to the DNA probes ß-actin, ß-tubulin, histone H2B, v-myc, c-src and α-globin were quantitatively measured by hybridization following exposure of the cells to the signals for 10, 20 and 40 minutes. The exposure of HL60 cells to any of the experimental conditions resulted in an increase in each measured transcript, with the exception of globin mRNA. The transcript for globin, a gene not normally expressed in this cell line, showed no quantitative change. The increase in the transcripts affected showed a non-linear pattern with respect to both time and amplitude. The same general pattern of response to time or amplitude change was observed for each of the transcripts affected. Since these are unrelated transcripts, the cellular response to elf EMFs appears to be a general one, possibly a reflection of cellular stress.

This work was supported by the Electric Power Research Institute (RP-2965-5,6), Office of Naval Research, Electro-Biology, Inc., and The Department of Energy.

A-3-8 **EFFECTS OF ALTERNATING MAGNETIC FIELDS (50 HZ) ON TUMOR CELLS IN SUSPENSION CULTURE.** Eberhard Liss* and Karl Brinkmann. University Institutes of Berlin (and Braunschweig), D-1000 Berlin.

We have tried to contribute to the question whether magnetic fields have deleterious effects on living organisms. We used ascites tumor cells which showed a high division rate in suspension culture with doubling times of 12 hours. These cells were used to investigate the influence of magnetic fields on the growth, which has proved

to be particularly sensitive to other influences, e.g. cytostatic active substances. The cell suspensions were slowly moved over several hours by rotating inside a coil. The incubation temperature was approximately 36.5°C. Field strengths between 0.1 and 25mT were applied. So far, no case of a significant difference between cells exposed to a magnetic field and control cells otherwise treated identically was determined. The frequencies of sister-chromatid-exchanges (SCE) were determined under the above described experimental conditions. We did not find any significant elevations of the SCE-frequencies in the presence of magnetic fields. SCE-frequencies are considered to be sensitive to mutagenic effects. In additional experiments cells were previously damaged with the cytostatic active substance Trenimon before exposure to magnetic fields. It had been expected that cells which had been pretreated in this way would be more sensitive to an additional exposure. Previously damaged cells clearly decelerated the cell growth and simultaneously increased the SCE-frequencies. However, exposure to magnetic fields did not reveal any additional changes in such cells either.

A-3-9 **EVALUATION OF THE POTENTIAL CARCINOGENICITY OF ELECTROMAGNETIC FIELDS.** Robert McGaughy and Doreen Hill. U.S. Environmental Protection Agency, Washington, DC 20460.

There have been many reports concerning the potential carcinogenicity of electromagnetic fields (EMFs). Because of its responsibilities for protection of the environment and the public health with respect to radiation, the Environmental Protection Agency (EPA) has undertaken a review of the currently available scientific literature on this topic. This extends previous reviews in 1984 and 1987 of the biological effects of radiofrequency (RF) radiation. A document has been written that examines current data from animal and epidemiological studies. The broad spectrum is covered, including studies on 60 Hertz, extremely low frequencies (ELF), and RF radiation. In addition, other supporting or ancillary information that may bear on the potential carcinogenicity of EMFs is examined, e.g., genotoxicity, mitosis and meiosis, transcription, translation and cell transformation, cell membrane interactions, intracellular responses, bone healing, intracellular enzyme responses, hormone effects, growth and differentiation, immunologic and hematologic effects, and central nervous system effects. Details on the report will be presented as well as information on how to obtain copies of the document from EPA.

SESSION B-1:	EPIDEMIOLOGY EXPOSURE ASSESSMENT
Moderators:	William Kaune and Kjell Mild

B-1-1 **COMPARISON OF EXPERT JUDGEMENT AND PERSONAL MONITORING DATA IN OCCUPATIONAL MAGNETIC FIELD EXPOSURE ASSESSMENT.** Dana P. Loomis*, Michael R. Flynn*, Sandy West*, William T. Kaune, Chu-Chih Chen*, and David A. Savitz*. Depts. of Epidemiology and Environmental Sciences and Engineering, University of NC, Chapel Hill, NC 27599.

Subjective assessments by experts are often used to estimate exposure in epidemiologic studies when quantitative measurements are lacking, but the validity of such judgements may be difficult to assess. In this study, 8-hour personal monitoring data obtained with the EMDEX instrument on 134 electric utility workers exposures to 60 Hz magnetic fields were compared to exposure assignments by experts. Utility managers and supervisors were asked to rank job titles on a low-medium-high scale with regard to average hours per week near energized equipment generating fields above "background". The monitoring data were then used to compute the mean and 90th and 95th percentiles of magnetic field exposure and the average proportion of time spent in fields greater than 3mG for each of the three groups. Both parametric and nonparametric analyses indicated for all exposure indices that 1) the three groups defined by the experts were statistically distinct and 2) the relative level of exposure in each was consistent with the rank assigned by the experts (e.g., mean exposure=1.0, 6.1, and 15.1 mG for low, medium, and high groups, respectively). These results suggest that experienced utility personnel can provide reasonably accurate qualitative assessments of current electromagnetic field exposures using expert judgement. It does not directly demonstrate that such judgements will be valid for the more difficult task of historical exposure assessment, but the results are encouraging for the success of that effort. Supported by the Electric Power Research Institute (Project 2964-05).

B-1-2 **ELECTRIC AND MAGNETIC FIELD MEASUREMENT PROJECT FOR UTILITIES - THE EMDEX PROJECT.** T. Dan Bracken, Richard F. Rankin*, J. Richard Alldredge*, and Russell S. Senior*. T. Dan Bracken, Inc. Portland, OR 97202.

The objectives of the EPRI EMDEX Project were: to transfer the EMDEX technology to utilities; to develop measurement protocols and data management capabilities for large exposure data sets; and to collect, analyze, and document 60-Hz electric and magnetic field exposures for a diverse population. Field exposure data were collected for utility employees at 59 sites in the US and three other countries by personnel from the participating organizations between October 1988

and September 1989. Specially designed sampling procedures and data collection protocols were used to ensure uniformity across sites. Subjects recorded in a simple logbook which of eight Work or three Non-work environments they occupied. Logbook entries were linked to the computer record of field measurements through clock time and recorded event marks. Approximately 47,000 hours of magnetic field and 20,000 hours of electric field exposure records taken at 10-second intervals were obtained, of which 70% were from Work environments. Exposures and time spent in environments have been analyzed by Primary Work Environment, by occupied environment, and by job classification. Distributions of the measurements and of the means of measurements over various time periods were very skewed with relatively few high values. Generally, the measured fields and exposures in the Generation, Transmission, Distribution and Substation environments were higher than in other occupational environments in utilities. The Non-work measurements and exposures for various categories were comparable. An extension of this project with data collection responsibilities distributed among utilities will investigate residential fields. EPRI RP2966-1

B-1-3 **MAGNETIC FIELD EXPOSURE ASSESSMENT OF ADULTS IN MAINE.** R. Kavet, Environmental Research Information, Inc., Palo Alto, CA 94306; J.M. Silva, Enertech Consultants, Campbell, CA 95008; D. Thornton*, Central Maine Power Company, Augusta, ME 04336.

Sixty-Hz magnetic field exposures were measured for 45 adult residents of Maine. Thirty of the subjects resided near rights-of-way (ROWs) with either 345- and 115-kV transmission lines, or ROWs with only 115-kV transmission lines; fifteen resided far away from any transmission lines. Personal exposure data for a 24-h period was acquired with the EMDEX. By using the EMDEX's event marker button, exposure was partitioned into Home and Away components. Also, three area measurements were taken for each subject using the personal exposure measurement period: (1) 24-h fixed site bedroom measurement with a second EMDEX; (2) Spot measurements in three rooms of every residence; (3) Spot measurements outside each residence. Qualitatively, the data show first, that average exposure for some subjects living far away from transmission lines can be as high or higher than exposure for subjects near lines. However, residence near transmission lines highly loaded during the measurement period appears to result in increased Home and total exposure relative to a far away population. Second, on an individual basis, Home exposure may deviate markedly from the exposure anticipated on the basis of an area measurement. Third, average exposure level while away from home was extremely uniform (at about 2 mG). On a quantitative level, Home exposure was correlated equivalently with Spot-In ($r=0.70$) and the 24-h fixed site measurement ($r=0.68$). Correlations of area measurements with total exposure were weaker because of the dilution effect of Away exposure ($r=0.64$ for Spot-In; $r=0.61$ for 24-h Bedroom). The data suggest caution before drawing inferences about Total personal exposure from area measurements.

B-1-4 **MAGNETIC 50 Hz BACKGROUND FIELDS IN HOUSEHOLDS.** Hermann Karner*, Andreas Stamm*, and Karl Brinkmann. Technical University, Dept. of High Voltage Engineering, D-3300 Braunschweig.

The distribution of 50 Hz magnetic background fields in households has been investigated. By means of a homemade meter three orthogonal field components could be separately recorded at time intervals of 12 seconds over a period of 24 hours. Measuring ranges reached from 100 nT up to 1 mT. The probe was set up away from domestic appliances in order to measure only the background level of the magnetic field. The location of the apartments was chosen in such a way that there were no overhead lines in their neighborhood. Due to a large number of measured values, we were able to eliminate short time variations. In this way a diurnal rhythm, which seems to correlate with the energy consumption in that residential district, occurred. In addition to that, magnetic flux densities were measured at several distances of cables with different voltage levels. Measured values were slightly higher at low voltages reaching values up to 4 μT at ground level. In this case, the drop of the flux density took place approximately in proportion to the distance. As for higher voltages, a faster drop could be observed.

B-1-5 **RESIDENTIAL MEASUREMENT OF MAGNETIC FIELD EXPOSURE: VARIABILITY BETWEEN ROOMS.** Kathleen Belanger*, Kathleen Sachse*, Karen Hellenbrand*, Michael Bracken*, and Brian Leaderer*. Yale University, School of Medicine, Perinatal Epidemiology Unit, 337 Crown Street, New Haven, CT 06511.

We examined the variability between measurements of magnetic field exposure in three rooms of the same residence. Forty homes in New Haven County were selected for the study. We placed an EMDEXC in each of three rooms in the home. In houses having more than one floor an effort was made to measure at least one room on each floor. The EMDEXC units recorded magnetic flux density every 60 seconds for 12-24 hours. In seven homes, at least one of the EMDEXC units failed, thus data from 33 homes was available for the analysis. Measurements of the mean magnetic flux density ranged from 0.2 mG to 3.1 mG. Overall 32 percent of the observations were less than 1 mG, 59 percent between 1 mG and 2 mG, and 8 percent greater than 2 mG. When three rooms in the same home were compared, the differences were less than .5 mG in 45 percent, between .5 mG and 1.0 mG in 39 percent and greater than 1 mG in 15 percent. Other factors that were analyzed included whether the residence was an apartment or a house, whether it had one floor or more than one and the specific rooms chosen for measurement. None of these factors appears to be related to either differences between residences, or to differences between rooms in the same residence.

B-1-6 **MEASUREMENTS OF ELF AND VLF ELECTRIC AND MAGNETIC FIELDS NEAR VDTs.** Monica Sandström, Kjell Hansson Mild and Berndt Stenberg*[1]. Natl. Inst. Occup. Health, Umea, and [1]Department of Dermatology, University of Umea, Umea, Sweden.

Skin symptoms among VDT-workers have been reported frequently in the last years. The cause for the symptoms have not yet been established. VDT-factors such as electric and magnetic fields, electrostatic charge, indoor climate factors and psychological factors have been suggested. From a screening study of 6000 office workers in northern Sweden a group of 150 VDT-workers were selected for a case-control study. Cases were defined as VDT-workers suffering from sensory and visual facial skin symptoms. Controls were VDT-workers free from such symptoms and matched for age, sex and living area. Measurements of both the environmental ELF electric and magnetic field in the office as well as the electromagnetic fields associated with the VDT at the workplace were performed. The methods used for these measurements were modified from the Swedish standard for measurement of near fields from computers and other office machines, and the method used will be described. The median values for the 50 Hz magnetic field in the investigated offices was 0.06 μT and for the ELF E-field in front of the VDTs (0.5 m) were 0.21 μT and 0.03 μT, respectively. A comparison between cases and controls regarding these various parameters will be discussed.

SESSION B-2: **CANCER**
Moderators: Christopher Cain and Reba Goodman

B-2-1 **AN ONCOLOGICAL STUDY WITH DMBA* ON RATS EXPOSED TO 50 Hz MAGNETIC FIELDS.** S. Buntenkötter*, K. Brinkmann, E. Zittlau*, R.Zwingelberg*, H.-J. Reinhard*, and M. Mevissen*. Tierarztliche Hochschule Hannover.

An oncological study on female rats (n = 96; Sprague-Dawley) was started in Hannover in 1987 and continued in 1989 as a part of an interdisciplinary research project on biological effects of electromagnetic fields (50 Hz). Adenocarcinomas were chemically initiated in experimental animals at an age of 52 days by means of gastral application. The animals were treated at weekly intervals with 4 doses of 5 mg DMBA, respectively. After adaptation and the first application of the carcinogenic substance to all animals 33 rats were exposed in a homogenous magnetic field with a flux density of 30 mT for 91 days. 63 animals served as controls; 36 of them were housed in sham coils in the laboratory and 27 animals were housed in conventional cages. The experimental animals were painlessly killed and examined for neoplasias. The following findings were established: incidence, number, and weight of the neoplasias. The evaluation of the test results did not indicate any

significant differences between exposed animals and sham exposed animals. Consequently, this oncological study does not reveal any tumor-promoting effects of electromagnetic fields (50 Hz; 30 mT) in case of a chemical carcinogenesis initiated by DMBA. * 9,10-dimethyl-1,2-benzanthracene = DMBA

B-2-2 **STUDIES OF 50 MHz ALTERNATING MAGNETIC FIELDS IN A RAT LIVER FOCI BIOASSAY.** Agneta Rannug*, Bo Holmberg, and Kjell Hansson Mild. Department of Toxicology, National Institute of Occupational Health, S-171 84 Solna, Sweden.

Known carcinogens, when administered to rats, produce preneoplastic changes in the liver that can be quantitated after a relatively short treatment period (2-3 months). Whether 50 Hz alternating magnetic fields could enhance the occurrence of preneoplastic liver foci in experimentally initiated male Sprague-Dawley rats was investigated. Exposure equipments were constructed for the generation of 50 Hz alternating magnetic fields with flux densities up to 0.5 mT. The animals were subjected to a two-thirds partial hepatectomy and 24 hrs later injected with a subnecrogenic and subcarcinogenic dose of dimethylnitrosamine (DENA) as an initiator. Magnetic field exposure was then applied as a potential tumour promotive factor for a period of 12 weeks starting 7 days after initiation. Phenobarbital was administered in positive control series as a known promoter. Magnetic fields were applied at four exposure levels 0.5 μT, 5 μT, 0.05 mT and 0.5 mT for 19-21 hrs/day. When magnetic fields were studied as foci promoter no systematic pattern in foci development was observed. [These studies were supported by a joint grant coordinated by the Swedish National Energy Administration, Stockholm (STEV project number C 066 902-1)].

B-2-3 **BIOLOGICAL EFFECTS IN MICE EXPOSED TO A 25-mT, 60-Hz MAGNETIC FIELD.** Wagih Z. Fam and Eva L. Mikhail*. Technical University of Nova Scotia, Halifax, N.S., Canada, B3J 2X4.

To find out if 60-Hz magnetic field can produce adverse biological effects on small mammals, three generations of laboratory mice of the SW-ICR strain were continuously exposed to a 25 mT (250 Gauss), 60 Hz alternating magnetic field. The first generation was introduced into the field at five weeks, and the second and third generations were conceived, born and raised in the field until they were sacrificed for tests at 120 days. The effect of the field on the various systems was investigated and the results were compared with those obtained from the corresponding control groups. Hematological system assessment was done through a bone marrow smear, a total blood count and a peripheral blood smear. Immune System tests included serum level of immunoglobulins and of complement in addition to tissue examination of the thymus, lymph nodes and spleen. Liver function was assessed through serum bilirubin, protein levels and serum enzyme levels. Reproductive ability was assessed through the number of born and surviving progenies. Histological

examination of the brain, liver, spleen, kidney, heart and lung was made for both the exposed and control animals. Preliminary results showed peripheral and bone marrow leukocytosis in some of the exposed animals; however, there was no evidence of leukaemic transformation as indicated by lack of increase of blast cells in the bone marrow and absence of immature forms in the peripheral blood. In addition, splenic hyperplasia and lymphadenopathy were noted in some of the exposed animals suggesting a possible immune system activation There was no gross or histopathological evidence of brain tumor or any other organ neoplastic transformation.

B-2-4 **EFFECTS OF RFR EXPOSURE ON CELL GROWTH AND DIFFERENTIATION: A STUDY UPDATE.** James Toler, David Banks, and Wesley Shelton. Bioengineering Center, Georgia Institute Technology, Atlanta, GA 30032.

This presentation reports on a study to investigate the effects of chronic low-level radiofrequency radiation (RFR) exposure on cell growth and differentiation. The protocol requires the exposure (1mW/cm^2, 20 hours daily, 7 days per week) of 200 mammary-tumor-prone mice (strain C3H/hej) to 435-MHz pulsed wave (1.0 μs pulse width, 1.0 kHz pulse rate) RFR for 18 months. Sham-exposure animals consist of 200 C3H/hej mice housed under identical conditions, but without radiation. Fifty C3H/hej mice (25 exposure, 25 sham-exposure) serve as sentinel animals for murine mycoplasma determinations. All laboratory activities, animal husbandry, data analyses, etc. are governed by Standard Operating Procedures. Each animal is examined weekly for the presence, size, and morphology of mammary tumors. After 18 months, a necropsy team will harvest tissues from the animals for complete histopathological examination. Statistical analyses of both in-life and histopathological data will determine the effects of RFR exposure on cell growth and differentiation.

The goals and initial efforts of this study were presented earlier. This presentation will provide a status report on the study one year later, with preliminary data on tumor onset time, tumor growth rates, animal weight curves, etc.

This study is sponsored by the USAF School of Aerospace Medicine under Contract No. F33615-83-K-0600.

B-2-5 **60 Hz MAGNETIC FIELD EFFECTS ON C3H10T1/2 FIBROBLASTS: ORNITHINE DECARBOXYLASE-ACTIVITY AND FOCUS FORMATION IN RESPONSE TO TUMOR PROMOTER.** C.D. Cain, W.J. Thomas*, and W.R. Adey. Jerry Pettis Veterans Hospital, Loma Linda, CA 92357.

As a classical "in vitro" tumor promotion model, C3H10T1/2 fibroblasts are responsive to tetradecanoylphorbol acetate (TPA). TPA treatment also causes a biphasic change in ornithine decarboxylase (ODC) activity (Djurhuus Int. J. Biochem. 19(6):495-501 1987). We previously reported the kinetics of this response from 2 to 24 hrs and the influences of a 60 Hz electric field, 10 mV/cm, (DOE Contractors Meeting, 1988). We now report that after a 1 h exposure to a 0.1 mT 60 Hz magnetic field and subsequent treatment with TPA (100 ng/ml), the ODC activity of exposed cells was an average 40% lower than that of unexposed cells at times 14 and 16 hrs measured from the start of TPA application. The ODC responses after 2-8 hr of TPA were similar for exposed and unexposed cells. TPA also causes focus formation of transformants in a co-culture system developed by Herschman (Science 234:1385-1388 1986). Pilot co-culture experiments suggested that a 60 Hz magnetic field (0.1 mT of 1 h exposures 4 times daily for 4 weeks) increased the number and size of TPA-induced foci. The 60 Hz magnetic field was generated by a solenoid coil (diameter of 0.8 meters and height of 0.8 meters) that was converted into a tissue culture incubator. The magnetic field deviated less than 4% in the volume of the cells. These data suggest that a 0.1 mT 60 Hz magnetic field can influence the ODC activity response of fibroblasts to a tumor promoter under tissue culture conditions consistent with tumor promotion protocols. Supported by the DOE Office of Energy Storage and Distribution, ED-AI01-85CE76260, and So. Cal. Edison.

B-2-6 **HETEROGENITY OF INHIBITORY EFFECT OF PULSED RF ON DIFFERENT MALIGNANT CELLS IN VITRO.** Darragh Foley-Nolan, Amanda McCann, and Desmond Carney. Department of Oncology, Mater Misericordiae Hospital, Dublin 7, Ireland.

We have previously reported a 32-40% inhibition of small cell lung carcinoma type H 146[1] and undertaken to establish whether other cell types can be inhibited using continuous exposure to pulsed 27.12 MHz at a maximum power of 3 mW/cm^2. As in the previous experiment controls and treated cells were incubated for 96 hours in separate identical incubators. A 25% inhibition was achieved on a breast line MCF 7 WR, a 35% inhibition achieved on a malignant melanoma line 234 and a 40% inhibition achieved on a skin cancer H 125 while an ovarian line OAW4 was inhibited by only 10%. In all cases the minimum number of separate experiments was 15 and a mean percentage result is given. In conclusion this study establishes

a heterogeneity of sensitivity to pulsed RF. Further studies to optimize field parameters are indicated.

Ref. 1 In vitro inhibition of small cell carcinoma of the lung cells by pulsed RF. D. Foley-Nolan et al. 11th AGM BEMS, Tucson 1989.

SESSION B-3: **PHYSIOLOGY**
Moderators: Jack Monahan and Richard Phillips

B-3-1 **SUMMARY OF ABSENCE OF GENOTOXIC ACTION OF RFR AT DIFFERENT FREQUENCIES ON MAMMALIAN CELLS.** Martin L. Meltz, *Victor Ciaravino, *Phyllis A. Eagan, *Steven T. Smith, Patricia K. Holahan, *James J. Kerbacher, and David N. Erwin. Department of Radiology, University of Texas Health Science Center, San Antonio, TX 78284, and the U.S.A.F. School of Aerospace Medicine, Brooks AFB, TX 78235.

A series of investigations have been undertaken to examine the ability of RFR at different frequencies, including 850, 1200, and 2450 MHz, at low or moderate power levels (and SARs), delivered either as continuous or pulsed wave exposures, to cause genotoxic events in mammalian cells. The cell lines were selected based on their appropriateness for the genotoxic endpoint examined. These have included induction of DNA repair synthesis in normal human diploid fibroblasts, mutation at the thymidine kinase locus in mouse leukemia L5178Y cells, and sister chromatid exchange (SCE) and chromosome aberration induction in Chinese hamster ovary (CHO) cells. Effects on cell growth rate were included in some of these studies. At the lower power densities, temperatures of the incubation medium did not increase above 37°C during the several hr exposure period. In the studies performed at moderate exposure values, temperatures of up to 40°C were achieved. In summary, from all of these experiments, there is no statistically significant evidence, or even suggestive evidence, that RFR under the conditions of exposure used can induce or interfere with DNA repair, or cause genotoxic damage measured using mutagenesis, sister chromatid exchange, or chromosome aberration assays. This research was funded by the U.S. Air Force.

B-3-2 **DEVELOPMENTAL TOXICITY STUDY IN RATS EXPOSED TO 60-Hz HORIZONTAL MAGNETIC FIELDS.** Donald N. Rommereim, Ramona L. Rommereim, Ray L. Buschbom and Larry E. Anderson. Battelle, Pacific Northwest Laboratories, Richland, WA 99352.

Generation, transmission and use of electricity has resulted in nearly ubiquitous presence of AC magnetic fields in the environment. Such a condition has prompted a study designed to determine the potential of magnetic fields to produce develop-

mental toxicity in rats. In two successive replicates, unexposed female rats were mated, then randomly assigned to one of three groups: ambient (0.087 μT), low (0.6 μT) or high (1,000 μT) sinusoidal horizontal magnetic fields. Pregnant animals were exposed for 20 hours per day, 7 days per week throughout gestation. Rats were weighed at 0,3,6,10,15 and 20 days of gestation. Dams were subsequently euthanized at 20 days of gestation and uterine contents were evaluated. Viable fetuses were weighed and examined for external, visceral and skeletal malformations. Fertility and gestational weight gain of dams were not affected by exposure. Pre- and post-implantation death loss did not differ among treatment groups. In replicate A the mean number of live fetuses per litter was significantly less for rats exposed to the 1000 μT magnetic fields when compared to animals in the low or ambient exposed groups. However, this decrease did not replicate nor did the combined values (both replicates) significantly differ among the groups. Percent of litters with malformed fetuses were 5.3, 3.4 and 4.6% for ambient, low and high exposed groups, respectively. Overall, developmental measures were not different among rats exposed to 0.087, 0.6 or 1000 μT 60-Hz magnetic fields. Research funded under EPRI Contract No. RP-2965-10.

B-3-3 **MECHANISTIC INVESTIGATION OF HISTOLOGIC FIXATION OF *MAMMALIAN CELLS BY MICROWAVE RADIATION.*** *Li-Ming Liu, Stephen F. Cleary, Guanghui Cao, and Randall E. Merchant*. Departments of Physiology and Anatomy*, Virginia Commonwealth University, Richmond, VA 23298.*

The technique of rapid histological fixation of cells and tissue by intense short duration exposure to 2.45-GHz microwave radiation has been well-documented. Typically, microwave-accelerated fixation involves exposure of histological specimens to SAR's of 1 kW/g or greater for periods of 20- to 100ms, resulting in fixation comparable to that requiring 2h or more in the absence of microwave exposure. During microwave-accelerated fixation energy absorption results in specimen temperature elevations of 10- to 20°C. Comparable temperature elevations induced by nonmicrowave heating are ineffective in tissue fixation, suggesting a microwave specific effect.

To investigate the mechanism of microwave-accelerated tissue fixation, mammalian cell (glioma RT-2) suspensions were exposed to 2.45 GHz continuous and pulse-modulated microwave radiation at SAR's of 2 kW/kg for periods of 3 to 15 s in a waveguide exposure chamber that permitted accurate specimen temperature measurement and control. The involvement of microwave-induced heating on cell fixation will be described. Mechanisms for microwave-accelerated tissue fixation will be discussed.

B-3-4 **RETINAL CHANGES IN THE PRIMATE FOLLOWING PULSED 2.45 GHz EXPOSURES.** H.A. Kues and D.S. McLeod*. The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723; J.C. Monahan, FDA Center for Devices and Radiological Health, Rockville, MD 20857; S.A. D'Anna* and G.S. Lutty*, The Johns Hopkins School of Medicine, Baltimore, MD 21205.

Previous work in our laboratory has demonstrated microwave-induced ocular changes to the corneal endothelium and iris vasculature, both with and without topical pretreatment with timolol maleate. In the present preliminary study, anesthetized cynomolgus monkeys were exposed over a 10-week period to pulsed microwaves (2.45 GHz, 10 μs, 100 pps) at average power densities of 5 or 10 mW/cm^2 with or without timolol maleate pretreatment. Following the series of 27 four-hour exposures, animals were injected with horseradish peroxidase (HRP) and sacrificed. Histological examination of ocular tissue confirmed our previous findings of increased iris vascular permeability to HRP. The subject exposed to 5 mW/cm^2 with no drug pretreatment demonstrated early degenerative changes in the photoreceptor outer segments. Extensive vacuolation of the outer retinal layers and focal retinal detachments were observed in the subject, who received 10 mW/cm^2 plus timolol maleate pretreatment. Increased vascular permeability was observed in the lamina cribrosa region of the optic nerve, along with nerve bundle degenerative change in all but the 5 mW/cm^2-only subject. In every case the drug-pretreated subjects displayed more extensive histopathological and permeability changes than non-drug animals exposed at the same power density. Some of the retinal changes we observed in this study could be age-related, but the data taken in totality suggest that microwave-induced retinal changes can occur in some situations at relatively low exposure levels.

Supported in part by the U.S. Navy and the Food and Drug Administration.

B-3-5 **PRENATAL EXPOSURE TO A LOW-FREQUENCY ELECTROMAGNETIC FIELD DEMASCULINIZES ADULT SCENT MARKING BEHAVIOR AND INCREASES ACCESSORY ORGAN WEIGHTS IN RATS.** Robert F. McGivern, Rebecca Z. Sokol, and W. Ross Adey. Harbor-UCLA Medical Center and Department of Medicine, Torrance CA 90509, and Pettis Memorial Veterans Hospital, Loma Linda CA 92357.

Pregnant Sprague-Dawley dams were exposed to a low-level, low-frequency pulsed electromagnetic (EM) field (15 Hz, 0.3 msec duration, peak intensity 8 gauss) for 15 min twice a day from day 15 through day 20 of gestation, a period in development that is critical for sexual differentiation of the male rat brain. No differences in litter size, number of stillborns, or body weight were observed in

offspring from field-exposed dams. At 120 days of age, field-exposed male offspring exhibited significantly less scent marking behavior than controls. Accessory sex organ weights, including epididymis, seminal vesicles and prostate, were significantly higher in field-exposed subjects at this age. However, circulating levels of testosterone, luteinizing hormone, and follicle-stimulating hormone, as well as epididymal sperm counts, were normal. These data indicate that brief, intermittent exposure to low-frequency EM fields during the critical prenatal period for neurobehavioral sex differentiation can demasculinize male scent marking behavior and increase accessory sex organ weights in adulthood.

Supported by National Institute of Alcohol Abuse and Alcoholism (AA 06478), UCLA Population Research Center (NICHD, HD 19445), the US Department of Energy, Office of Energy Storage and Distribution (DE-A101-85CE76260), the US Veterans Administration, the General Motors Research Laboratories, and the Southern California Edison Company.

SESSION B-4: **CELL BIOLOGY**
Moderator: *John Allis and Wesley Shelton*

B-4-1 **EFFECTS OF LOW POWER MICROWAVES ON ACh-ACTIVATED CURRENT IN MOUSE MUSCLE CELLS.** P. Bernardi, G. D'Inzeo, F. Eusebi, F. Farrelly, A. Giovanelli, F. Grassi, and S. Pisa. Department of Electronics, University of Rome "La Sapienza", 00184 Rome (Italy), Department of Experimental Medicine, University of L'Aquila 67100 L'Aquila (Italy).

It has been previously shown that microwave fields may affect the rate of acetylcholine (ACh) receptor (R) desensitization in muscle tissue [1]. In order to better quantify the incident field on the sample, a new exposure system has been developed. The system consists of a plexiglass vessel containing extracellular solution (30 ml in volume) placed at the end of an X band waveguide. In this experimental configuration the field in the vessel is attenuated exponentially with a measured attenuation constant of 0.33 mm^{-1}. The cells plated on a cover slip are placed at a determinate distance from the waveguide end, so that the evaluation of the power density impinging on the sample can be easily obtained from the measurement of the incident and reflected powers. Cultured muscle cells (C2 line) were exposed for up to 35 minutes to a microwave field at 10.750 GHz with power densities between 10 to 100 mW/cm^2. The whole cell current activated by the ACh transmitter was recorded by using a patch-clamp technique [1]. The whole-cell current response to the application in the bath of ACh consisted of an immediate fast rising phase (about 2nA of amplitude) followed by a biphasic decay. This falling phase was fitted with two exponentials, one fast and one slow. The comparison between experiments with and without EM field shows that the slow component of

the decay decreased in the exposed myotubes, thus reaching the base line faster. On the contrary, the peak amplitude of the ACh activated current as well as the fast component of the falling phase seem not to have been affected by the exposure to microwaves. This indicates that, under our experimental conditions, the conductance and open time of the ACh channel are apparently unaffected while the rate of desensitization of the AChR is greatly increased. These results obtained with a new exposure system and on a different biological sample agree with the previous set of experiments [1]. [1] G. D'Inzeo et al., Bioelectromagnetics, 9:363-372 (1988).

B-4-2 **CELLULAR ADRENERGIC RESPONSIVENESS AND SENSITIVITY TO ELECTROMAGNETIC FIELDS.** J.T. Ryaby, P. Duarte Alves, and A.A. Pilla. Bioelectrochemistry Laboratory, Department of Orthopaedics, Mount Sinai School of Medicine, New York, NY 10029.

Pulsing electromagnetic field (PEMF) signals induce differentiation in the murine melanoma cell line Cloudman S91. Previous work suggests that the cAMP second messenger system is involved in transduction of the PEMF stimulus. Recently, adrenergic receptors have also been implicated in the sensitivity to PEMF in cell systems such as melanoma, osteoblasts, and the pineal gland (melatonin secretion). In this study, evidence is presented that adrenergic receptors (both α and β) may regulate sensitivity to PEMF; and this may involve both homologous and heterologous desensitization mechanisms. Cloudman melanoma cells are grown in Hams F10 medium containing 15% Horse serum/2.5% Fetal Bovine serum and plated at a density of 20,000 cells/cm^2. MC3T3 osteoblasts were grown in α MEM containing 10% calf serum and plated at a density of 10,000 cells/cm^2. Partial synchronization and sensitization are performed by incubating cultures for 24 hours in serum free medium. PEMF was applied with 10 cm coils using a clinically active pulse burst signal (200 μsec polarity, 5 msec burst, overall frequency 15 Hz). dB/dt in the main polarity is 0.1 G/μsec corresponding to an induced electric field of 1 mV/cm. Adenylate cyclase activity is measured using ^{3}H adenine by the Salomon method. Tyrosinase activity is measured by ^3H_2O release from ^{3}H tyrosine. Anti-tyrosinase antibodies were a gift from Dr. V. Hearing (NIH). Pretreatment of melanoma cells with isoproterenol (a β-agonist) for 3, 6, or 24 hours did not decrease the PEMF stimulation of adenylate cyclase, which was 50 - 80% above control. However, 48 or 72 hour incubation with isoproterenol reduced the PEMF response to 20% above control. Epinephrine, an α-agonist, decreased the PEMF response at 24 hours. This indicates a potential role for both α and β adrenergic receptors in electromagnetic field sensitivity. However, MC3T3 osteoblasts, which show a 50 fold stimulation of adenylate cyclase by isoproterenol, do not respond to this specific electromagnetic signal. These results indicate that a positive response to adrenergic stimuli do not per se predict a positive response to an electromagnetic stimulus.

B-4-3 **EFFECT OF 60 Hz MAGNETIC FIELDS ON THE CLONOGENICITY OF HUMAN COLO 205 CELLS EVALUATED BY THE SOFT AGAR ASSAY.** *Peter C. Keng, S-T Lu, and Sol M. Michaelson. Department of Biophysics, University of Rochester School of Medicine and Dentistry, Rochester, NY 14642.

The objective of this study is to determine the mechanism of 60 Hz magnetic field induced growth disturbance in human cancer cells by assessing intrinsic alterations of cell growth in vitro. Human COLO 205 cells were maintained in RPMI 1640 with 10% fetal calf serum and 25 mM HEPES. Exponentially or near confluence growing cells were removed from plastic tissue culture flasks by trypsin and reseeded on 0.5-5% agar surface. Any cell aggregate containing more than 50 cells was considered to be a colony. Our preliminary results indicate that 1% agar appears to be the optimum agar concentration for in vitro exposure because it partially arrests the growth of COLO 205 cells without compromising the reproductive integrity of the cells. At higher concentration, the toxicity of agar becomes apparent. In addition, the colony forming efficiency in bilayer soft agar clonogenicity assay depends on cell density. Optimum cell density (1,000 cells) has been selected for the magnetic field exposure experiments. Experiments are in progress in which COLO 205 cells are exposed at 37.5°C to a 0.1 mT 60 Hz rotating magnetic field generated by Helmholtz coils inside identical incubators supplied with 6.5% CO_2. Concurrent sham exposures are performed in one of the incubators in which the coils are not energized, thus assuring double blind evaluation.

This work is supported by the Electric Power Research Institute, Contract RP2965-2.

B-4-4 **MICROWAVE-TRIGGERED LIPOSOMAL DRUG DELIVERY: INVESTIGATION OF A MODEL DRUG DELIVERY SYSTEM.** R.P. Liburdy, D. de Manicor, and B. Fingado. Bioelectromagnetic Research Facility, Lawrence Berkeley Laboratory, UC Berkeley, Berkeley, CA 94720.

Our laboratory has been investigating the interaction of model membrane systems with electric and magnetic fields (1-3). Membrane permeability increases have been observed in liposomal vesicle systems during in vitro exposures to microwave, time-varying magnetic, and static magnetic fields. Cholesterol and other non-phospholipid components of the bilayer are currently being investigated as parameters that play an important role in permeability changes induced by these fields. To determine if liposomal vesicles are responsive to microwave fields under in vivo conditions liposome vesicles were loaded with the drug gentamicin and used in drug delivery studies. To do this liposomes were placed subcutaneously as a depot in the limb of a rat and the area treated with 2450 MHz microwaves. Preliminary studies described here indicate that microwave fields significantly enhance release of

gentamicin, as measured by its appearance in the circulation. Supported by the Department of Energy, Office of Health and Environmental Research, under contract DE-AC03-76SF00098.

1. R.P. Liburdy, et al. Radiation Res. 103 (1985) 266-75.
2. R.P. Liburdy, et al. Radiation Res. 108 (1986) 102-13.
3. T.S. Tenforde and R.P. Liburdy, J. Theor. Biol. 133 (1988) 385-96.

B-4-5 **EFFECTS OF MICROWAVE FIELDS ON LIPOSOME PERMEABILITY: NON-PHASE TRANSITION LIPOSOME VESICLES.** R.P. Liburdy and B. Fingado. Lawrence Berkeley Laboratory, Bioelectromagnetics Research Facility, Research Medicine Division, University of California, Berkeley, CA 94720.

Microwave fields have been shown by us to influence the permeability of phase-transition liposome vesicles (Radiation Research 108: 102-111:1986). A marked increase in drug permeability occurred at temperatures below the phase transition temperature, Tc. This microwave effect (2450 MHz, SAR 6-60 mw/gm) was potentiated by plasma and by oxygen and was inhibited by antioxidants. We have also observed that the dielectric properties of these vesicles are altered at the phase transition temperature (Phys. Med. Biol. 33; 1309-1324:1988). Recently we performed experiments in which non-Tc liposomes, i.e. temperature insensitive, were treated with microwaves. Large unilammellar and multilammellar vesicles were formed from PI:PC and from partially hydrogenated forms of these phospholipids; 6-carboxyfluorescein or doxorubicin was employed as a drug release marker. We observed an approximate 50-55% maximal release when these liposomes were treated with microwaves compared to 10% in the absence of the field under isothermal conditions. Plasma enhanced this differential permeability. The presence of antibody in the bilayer did not have a significant effect on microwave release. Work supported in part by the US Department of Energy, Office of Energy Storage and Distribution, under contract DEACO37SFOOO98.

B-4-6 **ELECTROMAGNETIC STIMULATION OF BIOSYNTHESIS.** Martin Blank* and Reba Goodman**. Depts. of *Physiology and Cellular Biophysics, & **Pathology, Columbia University, 630 West 168th St., New York, NY 10032.

To determine the effects of EM stimulation on protein biosynthesis we have analyzed the newly synthesized proteins by 2D gel electrophoresis. (Blank and Goodman, Bioelectrochem. Bioenerg. 19:569-580, 1988 and 21:307-317, 1989). The results show:

- EM stimulated cells (in the ELF range) show relative increases in lower MW proteins.
- Heat Shock stimulated cells show similar patterns after subtracting the major heat shock protein band around 70kD. Similar patterns are also

found in the proteins of cells that have been injured by cutting or crushing.

- New proteins tend to have of lower MW, and pI values that are more symmetrically distributed than control proteins. The smaller new proteins are more highly charged, both positively and negatively, than control proteins.
- Missing proteins tend to have higher MW, but there is no one-to-one relation between missing and new proteins.
- There are large differences in the effects of 60 Hz and 72 Hz sine waves.

The changes in the MW distribution of proteins seen with several physical stimuli indicate a general response to stress. Additional specific responses reflect the nature of the stimulus (e.g., the new proteins synthesized during EM stimulation have properties that would be expected if they arose from an early termination of biosynthesis). Endogenous electrical stimulation during nerve excitation may be involved in long term potentiation and learning. We thank the ONR and EPRI (RP-2965-5) for their support.

B-4-7 **TIME-COURSE OF RNA SYNTHESIS FOLLOWING EXPOSURE OF NORMAL AND TUMOR HUMAN LYMPHOCYTES TO ELF PULSED MAGNETIC FIELDS (PMF).** M.L. Swicord[1], E.M. Czerska*[1], E.C. Elson[2], C.C. Davis[3], and J.T. Ning*. 1. Center for Devices and Radiological Health, FDA, Rockville, MD 20857, 2. Walter Reed Army Institute for Research, Washington DC 20307, 3. Department of Electrical Engineering, University of Maryland, College Park MD 20742.

Experimental work by R. Goodman, et al, (1983) has indicated that transcription is affected in cells exposed to ELF magnetic fields. To verify whether these results may be duplicated by us, and to extend these investigations to human tumor cells and longer durations of exposure, we exposed normal human lymphocytes separated from peripheral blood, or Daudi cells (established line derived from human lymphoma, characterized by a translocation of the c-myc oncogene and inclusion of Epstein-Barr sequence into the genome (ATCC) to the bone growth stimulating PMF pulse (EBI) at 15 Hz as used by Goodman, et al. Cells were either exposed or sham exposed for 15, 30, 45 minutes, 1, 2, 3, 6, 12, 24, 48, or 72 hours, and pulse labeled with tritiated ^{3}H-uridine 15 minutes prior to harvest. Heteronuclear (messenger precursor) and cytoplasmic (ribosomal) RNA was extracted and its radioactivity was determined. In the Daudi cell line heteronuclear RNA synthesis was increased and myc oncogene expression was enhanced when compared to sham controls, while normal cells remained unaffected. Prolongation of the exposure time results in successive enhancements or inhibitions of RNA synthesis at different timepoints.

B-4-8 **INFLUENCE OF ELECTROMAGNETIC FIELDS ON HUMAN PERIPHERAL LYMPHOCYTES IN CULTURE.** Gunter Obe*, Baochu Yang*. University-GH Essen, D-4300 Essen.

Human peripheral lymphocytes are cultured in the presence or absence of electromagnetic fields (50 Hz, 5 mT) in culture medium containing bromo- deoxyuridine. Differential staining of metaphases allows the determination of first (Ml), second (M2), and third (M3) metaphases in culture. By this the cell cycle progression of these cells can be measured. In addition, sister chromatid exchanges (SCEs) are analyzed. The frequencies of SCEs are not influenced in the presence of the field. In the presence of the field the cells cycle faster than in its absence. If this cell cycle effect is a real outcome of the exposure to the field it would be an explanation for the observed carcinogenic effects of electromagnetic field exposures. Another explanation for our results could be a slight temperature difference between control and exposed cultures of about 0.1°Celsius. This is presently being analyzed by incubating lymphocyte cultures at slightly elevated temperatures in the absence of electromagnetic fields.

B-4-9 **EXPOSURE OF HUMAN PERIPHERAL LYMPHOCYTES TO A NMR-TOMOGRAPH WITH AND WITHOUT PRETREATMENT BY TRENIMON.** Paul Eberle*, Susanne Diener*, and Barbel Geerken*. Institute of Human Biology, Dept. of Human Genetics and Cytogenetics, Technical University, D-3300 Braunschweig, FRG.

PH-stimulated human peripheral lymphocytes of 5 healthy donors, with and without pretreatment by Trenimon, were exposed to electromagnetic fields of a 1 Tesla-NMR-tomograph in two different experiments for 5 hours. By means of a body coil 11 image producing measurements were realized with different levels of intersections and different relaxation times. During exposure the cultures had been moved in and out the tomograph 5 times. The culture time was 72 hours with a permanent temperature of 37°C. Cytogenetic endpoints were: SCE-frequency (50 diploid metaphases in M2), chromosomal aberrations (100 diploid metaphases in Ml, 50 diploid metaphases in M2), and cell proliferation index (200 metaphases). Our results demonstrate that exposure of human peripheral lymphocytes to the NMR-tomograph, with or without pretreatment by Trenimon, does not affect the frequencies of SCEs and chromosomal aberrations. Yet, findings on cell proliferation kinetics do not allow definite conclusions, perhaps there is no influence.

SESSION C-1: **DOSIMETRY I**
Moderators: Steve Baumann and Charles Gottlieb

C-1-1 **AN EQUIVALENT CIRCUIT FOR MAXWELL'S EQUATIONS.** Carl H. Durney, Douglas A. Christensen*, and Paul McArthur*. Electrical Engineering, Bioengineering, University of Utah, Salt Lake City, UT 84112.

Using a standard Yee cell and finite differences, we have derived an electric circuit representation that is equivalent to Maxwell's equations. In this circuit representation, mesh currents are directly related to magnetic fields, and voltages to electric fields. The equivalent circuit consists of a parallel RC combination along each edge of a Yee cell, and an inductance cutting across each corner of the Yee cell. The equivalent circuit is valid both in the time domain and in the frequency domain. Writing equations for voltage and current for this equivalent circuit and then converting voltage to electric field and current to magnetic field gives exactly the finite-difference time-domain equations that are derived from Maxwell's equations. The equivalent circuit is not a low-frequency approximation; it is valid in any frequency range, including, for example, the optical range. The cell size must be small compared to a wavelength, of course, as in any finite-difference formulation.

This equivalent circuit should allow extension of the low-frequency impedance method of solving Maxwell's equations to higher frequencies, with the same advantages it has at lower frequencies. Furthermore, the equivalent circuit should provide additional insight into the nature of electromagnetic field characteristics, and it should facilitate the merging of field theory and circuit theory in cases, for example, where voltage sources are used to excite antennas.

C-1-2 **NUMERICAL COMPUTATION OF EM ENERGY DEPOSITION INSIDE HUMAN BODY FROM PORTABLE RADIO DIPOLE-ANTENNA BY COUPLED INTEGRAL EQUATIONS (CIE) AND 3-D MOMENT METHOD.** H.R. Chuang and Q. Balzano. Portable Communication Division, MOTOROLA, Ft. Lauderdale, FL 33322.

In this paper, a supercomputer simulation process is presented to numerically compute the EM coupling between a realistic human model and a radiating dipole-antenna of a portable radio at proximity. Coupled integral equations (CIE), Hallen's Integral Equation (HIE) for the dipole antenna and Electric Field Integral Equation (EFIE) for the human body model, are employed to formulate this EM coupling problem. Moment Methods with pulse-basis functions (1-D for the dipole wire-antenna and 3-D for the body model) are used to solve the unknown induced field (or current) numerically. A human model with a realistic shape was constructed and partitioned into about 1400 nonuniform cubic cells (about 300 cells modelling the

head) for numerical computation. The cubic-cell size ranges from 1.4 cm to 6.4 cm (the head part is partitioned with cubic-cell size from 1.4 cm to 2.8 cm). This modelling generates a huge complex/dense matrix equation with the order of about (4250 x 4250). The matrix order is equal to (NA + 3NB) of which NA is the number of 1-D segment modelling for the antenna and NB is the number of 3-D cubic-cell modelling for the body model. Symmetry can be applied to reduce the matrix-equation order to one half (about 2150 x 2150). However even with symmetry, it still needs about 10 Megawords computer core-memory to solve this complex and dense matrix equation by the Guassian Elimination Method (GEM). CRAY-2 supercomputer (128 Megawords core memory) is hence the best supercomputing platform for the huge computational problem (CRAY-XMP/48 has only 8 Megawords core memory which is not enough for solving this problem unless the 128 Megawords Second Semiconductor Memory (SSD) in CRAY-XMP can be accessed). A good agreement between numerical results and experimental measuring (840 MHz) on induced SAR (Specific Absorption Rate) inside the head of a phantom model and antenna patterns was achieved and will be presented in the meeting.

C-1-3 **EFFECTS OF FAT THICKNESS ON HEATING PATTERNS OF MICROWAVE APPLICATORS.** C.K. Chou, John A. McDougall*, K.W. Chan, and Kenneth H. Luk. Department of Radiation Research, City of Hope National Medical Center, Duarte, CA 91010.

Heat delivery and temperature control in tumors remain the most difficult technical problems in clinical hyperthermia. Heating patterns of various microwave and RF applicators are usually studied on homogenous muscle phantoms. Since the tumors are within the applicator near field, energy deposition is very complicated in a volume consisting of fat, muscle, bone, bolus material and air which have different dielectric properties and geometries. Heating patterns of the BSD MA-151 applicator on 5 phantoms with 0, 0.25, 0.5, 1 and 2 cm thick fat and 10 cm thick muscle were obtained. Hot spots at edges of this applicator were seen on all fat surfaces at 631 MHz and on 0.5 and 1 cm thick fat at 915 MHz. This is in contrast to the central elliptical heating on muscle only phantom. The heating patterns of the Clini-Therm applicators on muscle only phantom as indicated in the operations guide are elliptical with their major axis perpendicular to the E field. Thermograms of fat and muscle surfaces and the plane 1 cm below the muscle surface were taken on phantoms with 0, 0.25, 0.5, and 1 cm thick fat exposed with the Clini-Therm 10x10 cm medium applicator and bolus at 915 MHz. When exposed with no bolus and no fat, the patterns at 1 cm deep in muscle are similar to those in the operations guide. However, when bolus is used, the elliptical pattern is parallel to the E field and the elongation of the ellipse is proportional to the thickness of the fat. These results indicate that fat must be included for heating pattern determinations to be useful for clinical application.

C-1-4 **ASSESSMENT OF PULSED RF EFFECTS - FROM LOCAL ABSORBED DOSE IN ANIMALS TO EXPOSURES OF HUMANS.** Howard Bassen. Walter Reed Army Institute of Research, Department of Microwave Research D.C. 20307-5100.

Several classes of bioeffects of pulsed RF on animals cannot be assessed adequately using whole-body-average SAR data to define their threshold. Localized absorption in the head region can induce "microwave hearing", startle (or evoked body movements), and stun. The dosimetric quantity, regionally averaged specific absorption (SA), with units of Joules/kg, is the best dosimetric measure for these unique effects of pulsed RF. Dosimetric extrapolation allows estimates to be made of the external whole-body exposure levels that induce a "biologically" effective SA in the head region of humans. Effects induced by a single RF pulse or by a brief burst of multiple RF pulses (having a burst duration of less than 10 seconds) related directly to regional SA. The external exposure expressed in terms of fluence, (with units Joules/cm^2), correlates directly with induced regional SA. For brief exposures to a single burst of RF pulses, thermoregulation and thermodynamic factors in the head region (particularly the brain) are negligible modifiers of thermal effects. Recently published data (for 20 - 915 MHz) indicate that the regional SAR (in a volume comprising about 20% of the brain) exceeds the whole body SAR by factors much smaller than 20:1 ratio that is commonly used to relate maximum local SAR to whole-body average SAR. Using the published regional SAR data, dosimetric extrapolation was performed to estimate human exposure levels for a brief burst of RF pulses that can induce certain "biologically effective" SAs in the head region. For example, evoked body movements or startle in mice are induced by approximately 1000 J/kg, averaged over the animal's head region. A whole-body exposure of a human to fluences ranging from about 3 J/cm^2 at 60 MHz to about 100 J/cm^2 at 915 MHz will induce a regionally-averaged SA of 1000 J/kg in the human brain.

C-1-5 **SAR AND INDUCED CURRENT DISTRIBUTIONS FOR OPERATOR EXPOSURE TO RF DIELECTRIC SEALERS.** Jin-Yuan Chen, Om P. Gandhi and David L. Conover[1]. Department of Electrical Engineering, University of Utah, Salt Lake City, UT 84112; and NOISH[1], Cincinnati, OH 45226.

We have used the three-dimensional finite-difference time-domain (FDTD) method to calculate local, layer-averaged, and whole-body-averaged specific absorption rates (SARs) and induced current distributions in a sixteen-tissue, anatomically based, 5628-cell model of a human to assess operator exposure to RF sealers. Considered for the calculations are industrially relevant shapes and dimensions of commonly used RF dielectric heaters using parallel-plate and bar-type electrodes. Also used for the calculations are realistic postures of the human operators including extended arms to simulate working conditions or operator sitting on a wooden or metallic stool. Due to the high-intensity leakage fields in proximity to the RF

applicators, some of the highest SARs and induced currents are calculated for the hands and the ankles and, for sitting position, the knees. Steps should therefore be taken either to reduce the leakage fields or else shield the hands and the knees that need to be in the high leakage field regions.

C-1-6 **THE EFFECT OF WORKER POSTURE AND WORKPLACE VARIABLES ON FOOT CURRENTS FOR RF HEATER OPERATORS.** D.L. Conover, W.E. Murray*, R.M. Edwards* and D.M. Werren*, PAEB, DBBS, NIOSH, Cincinnati, OH 45226.

Data showing the effect of operator posture, workplace furniture and styrofoam floor material on foot current for RF heater operators in industry are presented. A total of 58 measurements were made with four subjects who were operating one type of RF heater in a workplace. Foot currents were measured in this study for exposure situations where reactive field coupling predominated (i.e., 10 to 100 MHz). The operators were located within one wavelength from RF heaters (within 1 m). Foot currents were determined as function of (1) the operator's hand position, (2) the type of stool/chair used, (3) the operator's posture (sitting vs. standing) and (4) the thickness of styrofoam between the operator's feet and the floor. The foot current was at a minimum with the operator's hands at his sides and increased by almost a factor of five (5) when the operator's hands were moved closer to the RF heater plates. In contrast, the foot current increased less than 70% for other variables discussed below. The foot current was greater for an operator sitting on a metal stool vs. on a metal folding chair. An operator sitting on a metal stool had a greater foot current than one standing on the floor. Foot current increased as the thickness of styrofoam (between the operator's feet and the floor) was decreased. In summary, the strong dependence of foot current on operator and workplace variables demonstrates that a standard procedure should be established for foot current measurements.

SESSION C-2 & 3 **POSTERS LISTED ON PAGES 73-104**
SESSION C-4: **DOSIMETRY II**
Moderators: William Feero and Richard Olsen

C-4-1 **TRANSIENT TEMPERATURE DISTRIBUTIONS IN A FINITE ELEMENT THERMAL MODEL OF THE PROSTATE REGION UNDERGOING HYPERTHERMIA TREATMENT.** Roy E. Adams* and Indira Chatterjee. Department of Electrical Engineering/Computer Science, University of Nevada, Reno, Nev. 89557.

The finite element method has been utilized to solve the bioheat transfer equation for the prostate region of the human body. A commercial finite element software package called ANSYS-PC/THERMAL has been used to obtain detailed tempera-

ture profiles in an inhomogeneous model of the CAT scan image of the prostate cross section. The detailed distribution of electromagnetic energy absorption in the model was obtained using the Finite Difference Time Domain (FDTD) technique. A tumor has been incorporated into the model. The model is surrounded by a water bolous of deionized water. An Annular Phased Array consisting of dipole antennas is the hyperthermia device assumed in the FDTD approach. The effect of vasodilation and of varying blood perfusion rates in both normal and tumor tissue on the detailed temperature profiles will be presented. This numerical model will predict effectiveness of the hyperthermia treatment in raising the temperature of the tumor to therapeutic values.

C-4-2 **USE OF BIOHEAT EQUATION TO CALCULATE TEMPERATURE IN A HUMAN BODY FOR HYPERTHERMIA WITH CAPACITIVE PLATE ELECTRODES.** Niel Orcutt and Om P. Gandhi. Department of Electrical Engineering, University of Utah, Salt Lake City, Utah 84112.

We have coupled the previously-described impedance method for calculating SAR distribution in a human body undergoing hyperthermia treatment for cancer with a finite-difference-time-domain computer solution to the bioheat equation. This combination of programs allows us to produce a computer solution for the temperature rise in the body undergoing treatment. We apply this method to a CT scan based model of the human body with an assumed tumor in the pelvic region and show detailed maps of the temperature in the body treated with round capacitive plate applicators driven with a 13.56 MHz radiofrequency current. The model of the body used consists of about 150,000 cubic cells in the body, each 0.87 cm per side, and about 450,000 air cells. We conclude that a system with a properly cooled bolus can selectively heat a region containing a tumor well inside the body. We also find that the most selective heating of the tumor is achieved by using smaller of the two applicators on the side of the body nearest the tumor and a larger application on opposite side of the body.

C-4-3 **PHOTONIC PROBES FOR MEASUREMENTS OF EMP-INDUCED FIELDS IN FULL-SIZE MODELS OF HUMANS.** Howard Bassen, Sam Rosenbloom*. Walter Reed Army Institute of Research, Department of Microwave Research, Washington DC 20307-5100.

Photonic (electro-optical) probes that are completely non-metallic have been developed previously by several laboratories to measure electric fields in the air near electromagnetic pulse (EMP) simulators. Modified versions of these probes have now been designed, fabricated, and specially calibrated to enable the measurement of the local electric (E) fields induced within biological subjects, during exposure to a single EMP pulse. Outdoor EMP simulators radiate a single pulse with a rise time of less than 10 nanoseconds, a duration of less than one microsecond, a

peak E field strength of 50 to 100 kilovolts per meter. Accurate EMP dosimetry with conventional E field probes with resistive data leads cannot transmit the fast risetime pulse to a remote receiver. Nonperturbing temperature probes cannot measure the infinitesimal amount of heating induced by the single pulse generated by EMP simulators once every few minutes. In contrast, implantable, photonic probes provide an exact replica of the amplitude waveform of the E field in a biological subject using nonperturbing glass or plastic fiber optic signal cables. Special numerical analyses and experimental verifications must be performed to enable the calibration of the implanted probe in terms of absolute E field strengths measured in tissue-equivalent materials. This calibration factor is applied when measuring fields induced in various simulated-tissue full-size models of humans and other biological subjects.

C-4-4 **ELECTRICAL CHARACTERISTICS OF A BABOON IN AN ELECTRIC FIELD.** Jeffrey H. Lucas and John L. Orr. Southwest Research Institute, San Antonio, TX 78228-0510.

During development of a blood-sampling cannula system for use in a high-intensity, 60-Hz electric field environment, important electrical parameters of a baboon on a grounded grate were measured. These parameters were: 1) the resistance of the baboon to ground and 2) the total current induced in the baboon by a vertical, 7.5 kV/m electric field. All measurements were performed through an electrode implanted subcutaneously in the baboon's back. The implanted electrode was a coiled section of surgical stainless steel wire approximately 1 cm in diameter. An insulated wire inside a shielded tether was used to connect the implanted electrode to the measurement equipment. The baboon resistance-to-ground was measured with the baboon on the metal grate using a voltage divider arrangement. A 1-volt sinewave was used to drive a 100 kilohm resistor in series with the electrode wire. The baboon resistance-to-ground served as the shunt leg of the voltage divider. The voltage input to the baboon was then measured to derive the baboon resistance-to-ground. In a separate experiment, the current induced in the baboon by the electric field was measured by insulting the baboon from ground and shunting the electrode wire to ground through a 1 kilohm resistor. The current induced by the electric field was calculated by dividing the voltage generated across the 1 kilohm resistor by the resistor value. For both experiments, the data was captured using a waveform analyzer and the rms average of the captured waveform was calculated. The raw voltage data was converted to units of current and resistance before plotting. The resistances measured ranged from approximately 2 kilohms to 200 kilohms while the baboon was on the metal grating. The lower resistances occurred more frequently when the animal was active during the day, while the higher resistances occurred more frequently at night when the animal was inactive. The electric field induced current ranged from 4 microamps/kV/m when the animal was in a sitting position to approximately 8 microamps/kV/m with the baboon in a biped standing

position. This project was sponsored jointly by the United States Department of Energy and the Central Research Institute of the Electric Power Industry of Japan as a part of contract DE-AC02-RA5O219 with Southwest Research Institute.

SESSION C-5:	**INSTRUMENTATION I**
Moderators:	William Feero and Richard Olsen

C-5-1 **NEW SENSORS FOR TRANSIENT AND PULSED FIELDS.** A. Thonsandote, M.A. Stuchly[1] S.S. Stuchly and J. Chrostowski[2]. Department of Electrical Engineering, University of Ottawa, Ontario, KIN 6N5, [1] Bureau of Radiation and Medical Devices, [2] National Research Council.

In evaluation of potential hazards of exposure to environmental electromagnetic fields and in characterization of fields produced by various devices there is a need to measure transient and pulsed electric and magnetic fields. We have developed three electric field sensors and one magnetic field sensor. In all three designs we aimed at obtaining the response proportional to the field rather than its derivative, as this provides for the optimal sensitivity and frequency bandwidth. The first sensor of the electric field consists of an electrically small sphere (or hemi-sphere) followed by a high input resistance amplifier. This sensor operates from 10 KHz to 350 MHz. Two other sensors are electro-optical. They use lithium niobate ($LiNbO_3$), or titanyl phosphate (KTP) crystals and are based on the polarimetric reflection. An electrically small sphere is employed as the antenna. The $LiNbO_3$ sensor operates from 70 KHz to 40 MHz. The magnetic field sensor on the other hand utilizes an electrically small square loop, a toroid current transformer and a low input impedance amplifier. It operates at frequencies from 5 KHz to 100 MHz. The design principles used for these sensors can be applied to develop sensors operating at other radiofrequencies with a similarly wide bandwidth. Details of the design and experimental results are presented.

C-5-2 **METERS FOR ASSESSMENT OF INDUCED BODY AND CONTACT CURRENTS AND STORED ENERGY IN ELECTROMAGNETIC FIELDS.** Om. P. Gandhi and Jin-Yuan Chen. Department of Electrical Engineering, University of Utah, Salt Lake City, Utah, 84112.

To reduce the internal SARs and potential for RF shock and burns, limits on body induced currents and contact currents have been proposed by IRPA, in Canada and more recently by IEEE SCC-28-IV. Though quantitative data are not presently available, it has also been recognized that transient discharge of stored energy from insulated or poorly grounded objects may result in startle reactions and burns. We have developed and will describe the following prototype meters for assessment of hazards for frequencies to 100 MHz. 1. A body current meter capable of measuring

currents (0-1000 mA) passing through the human feet. With a frequency response that is relatively flat (within +/- 0.5 dB) above 100 KHz and increased linearly with frequency below 100 KHz, as called for in the IEEE SCC-28-IV proposal, this meter is capable of assessing the hazard due to induced body currents for single or mixed frequency EM fields. 2. A contact current meter (0-300 mA) with internal impedance equivalent to that of the human body for a variety of contact conditions. This meter also has a relatively flat response for frequencies above 100 kHz and a response that increases linearly with frequency below 100 KHz as called for in the IEEE-SCC-28-IV proposal and can therefore be used in single or multiple frequency fields. 3. A stored RF energy meter capable of measuring open circuit voltages (0-5000 V) and short circuit currents (0-1000 mA) for frequencies up to 30 MHz.

SESSION D-1:	**MECHANISMS I** **JOINT SESSION WITH BIOELECTRO-CHEMICAL SOCIETY (BES)**
Moderators:	Martin Blank and Alessandro Chiabrera

D-1-1 **UNDERSTANDING FREQUENCY AND POWER WINDOWS WITH A DYNAMIC MULTISTEP REACTION MODEL.** C.J. Montrose and T.A. Litovitz. Vitreous State Laboratory, The Catholic University of America, Washington, DC 20904.

We have recently developed a dynamical model that describes EM field-induced transient augmentation of transcriptional activity. The model predicts that, as a function of the field strength, a maximum in the response (a "power window") measured at a fixed time following the start of exposure will be observed. In this paper we apply this thinking to account for (1) the enhancement in chick embryo abnormalities at intermediate exposure levels noted by Delgado et al. (J. Anat. 134, 533-551, 1982); (2) electric field strength dependence of the response of human lymphocytes to lectins reported by Cadossi et al. (Bioelectrochemistry and Bioenergetics 19, 315-322, 1988); and (3) the different dynamical increases in ornithine decarboxylase activity produced by microwaves modulated at 10-20 Hz (Byus et al., Cancer Research 48, 4222-4226, 1988) versus those modulated at 60 Hz (Kraus et al., this meeting). In each case the effect can be understood by recognizing that time for the transient response to reach its maximum value depends upon the magnitude and frequency of the exogenous field. This work was supported by the Walter Reed Army Institute of Research.

D-1-2 **ION DRIFT UNDER ELECTROMAGNETIC EXPOSURE AND ENDOGENOUS ELECTRIC FIELD.** Alessandro Chiabrera and Bruno Bianco*. Department of Biophysical and Electronic Engineering, Via all 'Opera Pia 11A, 16145 Genova, Italy.

The study of the Langevin equation, as a model of the Lorentz interaction of periodic low level electric and magnetic fields with charged biological messengers (ions), shows that endogenous forces are necessary in order for exogenous exposure to be effective. We prove that if the endogenous force is ignored, then any exogenous low level EM field is, in practice, ineffective with respect to noise, independent of any cyclotron resonant exposure condition. If the endogenous forces are able to confine the messenger in molecular crevices, such as binding sites, transmembrane channels and so on, they can smooth the thermal random motion of the messenger so that its intrinsic escape time becomes rather long. In this situation, we conjecture that the effects of low level exogenous exposure can build up and cause the messenger to drift away in a shorter time. We are able to transform the corresponding Langevin equation in a particular form of the Hill's equation, which is rather suitable for the search of instability conditions. So doing the first step in accomplished toward to proof or disproof of the conjecture.

D-1-3 **DISULFIDE REDUCTASE: A POTENTIAL ELECTROCHEMICAL RECTIFIER.** Johnathan L. Kiel*, Jill E. Parker*, and Stephen B. Pruett*. USAF School of Aerospace Medicine, Brooks AFB, TX 78235-5301 and Mississippi State University, MS 39762-5759.

A plasma membrane disulfide reductase in leukocytes produces extracellular thiols and regulates growth. Transformed mouse macrophages (RAW 264.7) showed a decrease in thiol production when treated (30 min) with low levels of LPS (10-100 pg/ml). This 24-hr post-exposure response was exacerbated by heating (with air or 2450 MHz, 100 W/kg, CW) to 42°C for 30 min. Maintaining the cells at room temperature (30-120 min) and then heating to 37°C for 30 min decreased both cell number and thiol production in 24 hrs. Washing cells prior to heating to 37°C, partially prevented the effects. 3-Amino-L-tyrosine (3AT), an antioxidant, and LPS at 37°C increased thiol production and cell numbers 2-4 times. 3AT at 37°C without LPS had no effect. Therefore, LPS activates peroxidation and thiol production and interacts with heating (microwave or conventional). Although the disulfide reductase mediates a one-way flow of electrons and protons out of cells (rectifies), cellular uptake of thiols and secretion of disulfides provide an electrochemical balance tightly regulated by feedback on cellular metabolism which prevents any net electromagnetic field effects. (Supported in part by the USAF Office of Scientific Research).

D-1-4 **A STOCHASTIC MODEL FOR THE ANALYSIS OF IONIC CHANNELS GATING UNDER ELECTROMAGNETIC EXPOSURE.** G. D'Inzeo, S. Pisa*, L. Tarricone*. Department of Electronics, University of Rome "La Sapienza", 00184 Rome (Italy).

Several experimental results have shown the existence of effect of electromagnetic (EM) fields on ionic channels and on the current fluxes across them. This consideration justifies the development of accurate models of the membrane channels' behavior studying the EM field interaction. This work proposes a stochastic model of the channel gating that allows the simulation of the behavior of calcium, sodium and potassium voltage-dependent channels. The channel is considered a non deterministic device with a certain set of states (open, close, inactivated) that flips from one state to another. The probabilistic theory by Hodgkin and Huxley is used to determine the kinetic constants of the process. The sum of many realizations of the process allows the evaluation of the mean value and of the fluctuations (noise) of the channel conductance. The proposed model has been checked in the case of no EM exposure, making a comparison between theoretical results and some experimental data. The EM action has been simulated by varying the voltage dependent parameters of the model according to the time-variations of the field. The model has been studied in the extremely low frequencies range, although it may be used for a wide range of frequencies. Variations in the channel conductance due to the EM stimulus have been observed. They depend on both the frequency and the amplitude of the field. This result agrees with some experimental data, despite, preceding theoretical works based on a deterministic method, found no dependence on the field frequency. Variations in the noise-current spectra are observed too.

D-1-5 **CELL CHANNEL MODEL SUGGESTED BY DATA LINKING BIOLOGICAL SYSTEMS AND ELF FIELDS.** B. R. McLeod[1] A. R. Liboff[2], and S.D. Smith[3]. [1]Dept. of Electrical Engineering, Montana State University, Bozeman, MT 59717. [2]Dept. of Physics, Oakland Univ., Rochester, MI 48063. [3]Dept. of Anatomy and Neurobiology, Univ. of Ky, Lexington, KY 40536-0084.

When certain biological systems have been exposed to ELF magnetic fields, chosen such that the dc field magnitude and ac field frequency satisfy the cyclotron resonance conditions for a specific ion, biosystem responses have been similar to that which could have been expected by altering the transmembrane flow of that specific ion. The data prompted an examination of the membrane channel as a potential interaction site since one might find unhydrated, specific ions in the channel, and the ions may exist in a relatively collision free, quantized energy environment. Since cells at equilibrium tend to show only a weak response to ELF fields, this may suggest that special "emergency" channels form or open when the

biosystem is stressed. Known adaptive channels include certain channels that appear to activate based upon intracellular ion concentration, others that become available during a specific portion of the mitotic cycle, and yet others that activate depending upon the age of the biological system as it develops from an embryo to an adult. A model for this special channel is thus suggested and calculated results include a predicted resonant frequency response, a single, broad amplitude window, and a channel geometry dependent preference for odd harmonics of the ELF fundamental frequency.

SESSION D-2:	**MECHANISMS II** **JOINT SESSION WITH BES**
Moderators:	Abe Liboff and Mays Swicord

D-2-1 **ACTIVATION OF SIGNAL TRANSDUCTION IS REQUIRED FOR ALTERATION OF CA^{2+}- METABOLISM IN RAT THYMIC LYMPHOCYTES BY A SINUSOIDAL 60 HZ MAGNETIC FIELD.** Jan Walleczek and Robert P. Liburdy. Bioelectromagnetics Research Facility, Research Medicine Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720.

A 60 min-exposure of Concanavalin-A (Con-A) activated rat thymocytes to an ELF magnetic field (MF; v = 60 Hz, induced E_{peak} = 1.0 mV/cm) lead to a 2.7-fold ($p<0.05$) increase in Con-A triggered $^{45}Ca^{2+}$ net transport across the cell membrane compared to non-exposed, temperature-matched cells. In contrast, $^{45}Ca^{2+}$ flux remained unaltered during field exposure of quiescent, non-activated thymocytes. These results indicate (i) that non-thermal levels of ELF MFs can stimulate Ca^{2+} net transmembrane flux by 1 hour and, (ii) that under these conditions signal transduction activation is an essential requirement for this effect on Ca^{2+}-metabolism. Alteration of Ca^{2+} transport may represent a common pathway for electromagnetic field coupling to cellular systems. The significance of the concept of biological activation in relationship to electromagnetic field-induced bioeffects will be discussed. This work is supported by the Department of Energy, Office of Energy Storage and Distribution, under contract De-AC03-76SF00098. J.W. is supported by the Deutsche Forschungsgemeinschaft (WA 680/1-1).

D-2-2 **THE EFFECTS OF ALTERNATING CURRENTS ON Na,K-ATPase FUNCTION.** Martin Blank and Lily Soo. Dept. of Physiology and Cellular Biophysics, Columbia University, 630 West 168th Street, New York, NY 10032.

The frequency dependent accumulation of cations by erythrocytes in AC fields involves the membrane Na,K-ATPase. We have shown (M. Blank, J. Electrochem. Soc. 134:343-346 and 1112-1117, 1987) that AC across membranes causes frequency dependent ion concentration changes that could influence the activity of the Na,K-ATPase in the same frequency range. We have studied ATP splitting by the enzyme when AC (over an amplitude range of 1mV -1V and a frequency range of 10-100,000 Hz) flows through the Na,K-ATPase suspension via platinum electrodes/salt-impregnated agar gels. The AC signals decreased ATP splitting by the normal enzyme, with the maximum effect at 100 Hz and .5 mAmp/cm^2. The AC signals also increased the enzyme activity, when the control activity was lowered in three different ways: by natural decay of the enzyme during storage under refrigeration, by lowering the temperature, and by introducing partially effective concentrations of ouabain. The quantitative dependence of the enzyme activity in the ouabain experiments suggests that AC antagonizes the inhibitory effect of ouabain by increasing the effective K^+ ion concentration. The present experiments show that AC can inhibit as well as activate this enzyme, and that the effects can be explained by variations in ion activation.
We thank the ONR for their support.

D-2-3 **LOCALIZED MICROWAVE ABSORPTION IN DNA SOLUTIONS IS REVEALED BY THE STATIC CONDUCTIVITY.** Miguel Penafiel*, Robert Meister*, and T.A. Litovitz. Vitreous State Laboratory, The Catholic University of America, Washington, D.C. 20064.

The response of biological cells to electromagnetic fields can be analyzed on two levels, the response of the cell and its environment, and the response of components internal to the cell. Among these components is DNA which is present in the cell as a polyelectrolyte. In common with other polyelectrolytes it contains a condensed ion layer, the nature of which is dictated by the distribution of charges along the entire molecule. The importance of the condensed ion layer in causing non-uniform microwave absorption has been shown in a companion paper. We shall show that the density of condensed counter ions and thus the magnitude of the microwave absorption can be determined by a simple measurement of the dc conductivity of DNA solutions. Together with a spectrophotometric determination of the concentration of DNA, this leads to the prediction of the extent of the localized microwave absorption in the immediate vicinity of the DNA molecule. This work was supported by the Walter Reed Army Institute of Research.

D-2-4 **ON THE ORIGIN OF MICROWAVE ABSORPTION IN DNA SOLUTIONS.** Babak Saif*, T. A. Litovitz, R.K. Mohr* and C.J. Montrose. Vitreous State Laboratory, The Catholic University of America, Washington, DC 20904.

To clarify the mechanisms of microwave absorption of aqueous DNA solutions, dielectric absorption and dispersion measurements were made over a frequency range of 1 MHz to 1 GHz. The relaxation of the conductivity observed in this region was fit to a sum of three Debye relaxations (with relaxation frequencies of 7, 33, and 200 MHz) as well as to a log Gaussian distribution of relaxation times. The relaxational contribution to the conductivity appearing in this frequency region was consistent with assuming that the microwave absorption was due to counter-ions condensed around the DNA molecule. This interpretation suggests that the deposition per unit volume of microwave energy is as much as 100 times greater in the immediate vicinity of the DNA molecule than in the bulk solution. It may be important to consider this when SAR values (which represent an average over the entire specimen) are used to set "safe" exposure levels. This work was supported by the Walter Reed Army Institute of Research.

D-2-5 **EFFECTS OF ACUTE AND REPEATED MICROWAVE EXPOSURES ON BENZODIAZEPINE RECEPTORS IN THE BRAIN OF THE RAT.** Henry Lai, Monserrat Carino*, Akira Horita, and Arthur W. Guy. Department of Pharmacology and the Center for Bioengineering, University of Washington School of Medicine, Seattle, WA 98195.

We studied the effects of acute (45 min) and repeated (ten daily 45-min sessions) microwave exposures (2450 MHz, 1 mW/cm^2, average whole body SAR of 0.6 W/kg, pulsed at 500 pps with pulse width of 2 μs) on the concentration and affinity of benzodiazepine receptors in the cerebral cortex, hippocampus, and cerebellum of the rat using the receptor binding assay with ^{3}H-flunitrazepam as ligand. Immediately after exposure, an increase in the concentration of receptor was observed in the cerebral cortex but no significant effect was observed in the hippocampus and cerebellum. No significant change in binding affinity of the receptors was observed in any of the brain regions studied. In rats subjected to repeated exposure, no significant change in receptor concentration was found in the cerebral cortex immediately after the last session of microwave exposure suggesting that adaptation occurred after repeated exposure. Our data also show that handling and exposure procedures in our experiments did not significantly affect benzodiazepine receptors in the brain. Since benzodiazepine receptors in the brain are involved in anxiety and stress responses, our data support the hypothesis that low-level microwave irradiation is a "stressor."

SESSION E-1:	**SYMPOSIUM 2** **MAGNETIC RESONANCE IMAGING**
Organizers:	Robert Liburdy and Emanuel Kanal

E-1-1 **SAFETY CONSIDERATIONS IN MAGNETIC RESONANCE IMAGING.** Emanuel Kanal. The Pittsburgh NMR Institute 3260 Fifth Avenue Pittsburgh, PA. 15213.

Over the past five to ten years magnetic resonance imaging has blossomed into an invaluable imaging modality in the diagnostic armamentarium of the radiologist. The widespread increase in utilization of this device and diagnostic knowledge associated with its use have not, however, been paralleled by a similar understanding of the safety considerations associated with magnetic resonance examinations. There are, in fact, multiple areas of potential hazard associated with the magnetic resonance imaging process, including the biologic and/or mechanical effects from the static fields and static gradient, possible induced currents from the magnetic field gradient switching, direct burns and/or RF induction thermal injuries from currents that are induced within conductors or conductive tissue by the RF excitation pulses used in clinical MR, and possible biologic effects of the RF magnetic field oscillations. Information available from the Food and Drug Administration as well as a previous industry survey reveals multiple incidents of note related to MR imaging environments, including, but not limited to, projectile effects from ferromagnetic projects, magnetophosphene induction, and thermal injuries to patients and devices within MR imaging and research devices of up to 4+ Tesla static field strengths. In addition, a survey is about to be distributed to all magnetic resonance technologists and nurses in the United States addressing several health-related issues. These include pregnancy, fertility, menstrual regularity, and miscarriage rates in an attempt to perform the first part of an epidemiologic study to assess these topics for this population of health professional working in and around the environment of magnetic resonance imaging systems.

E-1-2 **MR PHYSICAL ENVIRONMENT.** Daniel J. Schaefer. General Electric Medical Systems, Milwaukee, WI 53201.

Magnetic resonance (MR) imaging requires a static magnetic field, time varying magnetic field gradients, and a radiofrequency (RF), magnetic field. Static magnetic field strengths range from 0.02 to 2.0 Tesla (4.0 Tesla in experimental systems). Gradient fields usually vary at less than 20 Tesla/sec. However, echo-planar techniques could benefit from much higher rates. Axial gradients typically produce the highest flux in the body. Transverse gradients usually reverse signs through the body resulting in lower net flux. Unintentionally, time varying gradients reduce acoustic noise. Many MR scanners use quadrature RF excitation

to improve image quality and to half power deposition compared to linear. Stirring of any potential "hot-spots" is an advantage of quadrature excitation. The RF electric field may result in coil tuning changes with patient loading. Coil designs reduce relative electric field magnitude. Because the RF field is principally magnetic, RF power is deposited peripherally. Primary safety issues include ascertaining thresholds for static field effects, for gradient-induced peripheral nerve and cardiac stimulation, for acoustic noise effects, and for average and peak thermal effects. Future studies in these areas and on the effects of conductive objects (e.g., monitoring equipment, implants, and prostheses) in the MR environment would be useful.

E-1-3 **FDA SAFETY GUIDANCE FOR MAGNETIC RESONANCE DEVICES.** T. Whit Athey. Center for Devices and Radiological Health, Food and Drug Administration, Rockville, MD 20857.

In 1988 the Food and Drug Administration (FDA) reclassified magnetic resonance (MR) devices from Class III (highest level of premarket regulation) to Class II (medium level of premarket regulation). As a part of the reclassification process, FDA developed a set of "Safety Parameter Action Levels" which set forth guidance on levels of static magnetic fields, dynamic magnetic fields, and radio frequency magnetic fields which FDA considered to be below the level of concern. The emphasis in the development of these action levels was upon specification of the fundamental physical and physiological quantities of concern, allowing individual manufacturers flexibility in applying the guidance to specific devices. A summary of the FDA guidance and its rationale is presented.

E-1-4 **REVISED ADVICE ON LIMITS OF EXPOSURE OF PATIENTS AND VOLUNTEERS DURING CLINICAL MR DIAGNOSIS IN THE U.K.** Richard D. Saunders and Zenon J. Sienkiewicz. National Radiological Protection Board, Chilton, Didcot, Oxon, United Kingdom.

Considerable experience has been gained with magnetic resonance (MR) diagnostic equipment since the Board issued advice on acceptable limits of exposure (NRPB, 1984. ASP 5, HMSO, London); in addition, further scientific data on human responses during MR exposure have become available. After consultation in 1988 with clinicians, manufacturers and various scientific bodies and individuals concerned with MR safety, the Board circulated for comment a draft proposal for revised advice on limits of exposure during clinical MR diagnostic procedures. A two tier system of restriction was proposed: a lower level identified exposures considered to be safe and which could be exceeded with adequate physiological monitoring and medical supervision; an upper level identified exposures which would be inadvisable to exceed. Briefly, exposure to static magnetic fields of up to 2 T was considered safe, with exposure to up to 4 T allowed under controlled conditions. For the pulsed gradient fields, exposure to rms rates of change of

magnetic flux density of up to 20 T s^{-1} for dB/dt periods exceeding 120 μs was considered safe, with higher rates of change allowed for shorter periods. Under controlled conditions, it was suggested that exposure to higher rates of change of flux density be allowed for dB/dt periods of less than 3 ms. Exposure to radiofrequency magnetic fields at whole body SARs of up to 1 W kg^{-1} was considered safe, with exposure at up to 2 W kg^{-1} allowed for some patients under controlled conditions. These draft proposals will be described in greater detail. Comments received from scientists, clinicians and manufacturers will be discussed, along with some of the difficulties and uncertainties in setting appropriate limits for these diagnostic techniques.

E-1-5 **MRI-COMPATIBLE MONITORING SYSTEMS.** Frank G. Shellock. Cedars-Sinai Medical Center, Div. of MRI and Department of Radiological Sciences, UCLA School of Medicine, Los Angeles, CA 90048.

MRI-compatible monitoring is required for the safe utilization of MRI in patients that are sedated, anesthetized, or critically-ill. In addition, this equipment is crucial for investigations of MRI-related bioeffects. Conventional monitoring equipment was not designed to operate in the MRI environment where static, gradient, and RF electromagnetic fields can adversely effect the operation of these devices. Besides being influenced by the static magnetic field, monitors may be adversely affected by electromagnetic interference from the gradient and RF pulse from the MRI scanner. Certain monitors emit spurious "electromagnetic noise" that can result in moderate to severe imaging artifacts. Of further concern is the fact that some monitoring equipment can be potentially harmful to human subjects if special precautions are no followed. At the present, virtually every physiologic parameter that can be obtained under normal circumstances in the intensive care unit or operating room is capable of being monitored during MRI with specially modified MRI-compatible equipment including heart rate, systemic blood pressure, intracardiac pressure, end-tidal carbon dioxide, oxygen saturation, respiratory rate, skin blood flow and temperature. This presentation will discuss the implementation of these various devices.

E-1-6 **LOCAL AND GLOBAL THERMAL RESPONSES TO MRI FIELDS.** Christopher J. Gordon. Neurotoxicology Division, U.S. EPA, Research Triangle Park, NC 27711.

In the development of safety guidelines for MRI devices, it is necessary to assure that local and global increases in tissue temperature do not exceed hazardous levels. Exposure guidelines in the U.S.A. restrict core temperature (T_c) from increasing over 1.0°C and skin temperature (T_{sk}) from exceeding 40°C. In the U.K. it is proposed that T_c elevations be limited to 1.0°C with local SAR in 0.1 kg of tissue not exceeding 10 W/kg in the head/trunk and 20 W/kg in the in the extremities for exposures of 0.1 hr. The relatively few studies suggest that these temperature limits

are never reached under most exposure scenarios. Whole-body SAR's < 0.4 W/kg appear to have little effect on thermoregulation. SAR's of 0.4 to -2.0 W/kg result in significant elevations in T_c and T_{sk}; however, these temperature elevations are slight and appear to be safe for most subjects. SAR's of 4.0 W/kg result in a 0.3°C elevation in T_c and up to a 3.0°C rise in T_{sk} within 20 min of exposure. Because of the peripheral energy deposition during MRI procedures, the formation of "hot spots" is expected to be of little significance. However, there are several uncertainties in this field which have not been addressed, including the problem of perception of RF induced thermal injury, the effect of various metal prostheses on the magnification of RF heating during MRI, the role of compromised thermoregulatory function (e.g., fever, responses of the very young or aged), and the sensitivity of thermally susceptible tissues and organs such as the CNS, cornea, and scrotum,

E-1-7 **PREDICTION OF PERIPHERAL NERVE AND CARDIAC EXCITATION THRESHOLDS BY TIME VARYING MAGNETIC FIELDS.** J. Patrick Reilly. The Johns Hopkins University, Applied Physics Laboratory, Laurel, MD 20723.

Time-varying magnetic fields from magnetic resonance imaging (MRI) devices are capable of inducing electric fields and circulating currents within biological media. This presentation reviews principles of magnetic excitation for peripheral nerves and the heart. Biophysical mechanisms and models are used to define thresholds of excitation in terms of the E-fields induced within the medium. These thresholds are related to dB/dt exposure criteria using magnetic induction principles. The relative sensitivity of nerve and heart to dB/dt exposure depend on excitation time constants of the respective tissue, and their geometric arrangement within the body. While the minimum excitation thresholds of the most sensitive nerve and cardiac tissue do not differ greatly, their magnetic thresholds can be disparate due to factors related to their location within the body, and their respective waveform sensitivity.

E-1-8 **EVIDENCE OF NERVE STIMULATION BY TIME-VARYING MAGNETIC FIELDS.** Mark Cohen and Robert Weisskoff. Advanced NMR Systems, Inc., Woburn, MA 01801.

For single excitation, or "Instant", Magnetic Resonance Imaging the minimum scan time is limited by the maximum magnetic field gradient amplitude and its switching speed. In the course of the design of a novel high-speed imaging system we constructed a gradient coil and power system capable of sinusoidal dB/dt of greater than 66 Tesla/sec RMS. At this dB/dt no gross effect or changes in the electrocardiogram were detected in a canine. Two volunteers, who were part of the design team, reported marginal (i.e. apparently near threshold) cutaneous stimulation at a dB/dt of 61 Tesla/second RMS. The effects were described as similar to tactile stimulation and were detected in the small of the back, the medial thigh and the bridge of the nose. They were in no cases noxious or painful and no residual effects

were seen on medical follow up. In subsequent experiments with the dB/dt reduced to our imaging operating point of approximately 33 Tesla/sec, which was selected to be nominally equal to the FDA guideline, similar effects were not reported.

SESSION E-2: MAGNETIC RESONANCE IMAGING
Moderators: Jerome Beers and Asher Sheppard

E-2-1 MAGNETIC RESONANCE IMAGING INCREASES THE BRAIN SPACE OF 153 GADOLINIUM DIETHYLENETRI-AMINEPENTAACETIC ACID IN RATS. Frank S Prato*[1], Roger H Frappier*[1,2], Richard R Shivers*[2], Martin Kavaliers[3], Pamela Zabel*[1], Dick J Drost*[1], Ting Y Lee*[1]. Department of Nuclear Medicine and Lawson Research Institute, St. Joseph's Health Centre[1], Department of Zoology[2] Division of Oral Biology, Faculty of Dentistry[3], University of Western Ontario.

In a qualitative electron microscopy study, we initially reported that exposure of rats to a standard clinical magnetic resonance imaging (MRI) procedure temporarily increased the blood-brain barrier (BBB) permeability to horseradish peroxidase. Subsequent quantitative studies by other investigators using various tracers and different exposure conditions have resulted in reports which either support or contradict our original findings. In this study, we quantitatively support our initial finding. Rats were injected intracardially with radio-labelled diethylenetriaminepentaacetic acid ([^{153}Gd]DTPA, a chelate which has low BBB permeability), in the middle of two sequential 23.2 min MRI exposures. Exposed rats (n=2l) showed significantly greater (29%, p=.0.006) retention of [^{153}Gd]DTPA than sham exposed rats (n=22) one hour after the end of the last 23.2 min exposure. It is suggested that differences between investigators may relate to either differences in animal preparation or magnetic field exposure conditions or both. These findings support our earlier observation that magnetic fields may alter BBB permeability.

E-2-2 PERMEABILITY OF THE BLOOD-BRAIN BARRIER (BBB) OF THE RAT TO ALBUMIN IS NOT SIGNIFICANTLY ALTERED BY NUCLEAR MAGNETIC RESONANCE IMAGING (NMRI) FIELDS. [1]Stephen M. Ross, [1]Robert P. Liburdy, [2]Thomas F. Budinger, [3]Lief G. Salford, [3]Arne Brun, [3]Betil R.R. Persson, [2]Mark S. Roos, [1]Darlene J. de Manincor and [2]Kathleen M. Brennan. [1]Bioelectromagnetics Research Facility, [2]Research Medicine Division, Lawrence Berkeley Laboratory, University of California, Berkley, CA 94720: and [3]Division of Experimental Neurooncology, University Hospital, Lund University, S-221 85 Lund, Sweden.

Concern exists that NMRI fields may alter the permeability of the BBB. We have examined the permeation of bovine serum albumin (BSA), which ordinarily has a

near-zero BBB-permeability, in the presence of NMRI fields. We have exposed Sprague-Dawley rats (weight 280g, 8-9 wk) to NMRI fields typical of multi-slice, multi-echo imaging sequences. NMRI field components were: static, 2.3 T; switched gradient dB/dz = 10 mT/m, with the animal's head positioned 100 mm from gradient center so that B_{peak} = 1 mT and dB/dt = 1 T/s; RF, pulsed 64 μT, 100 MHz carrier. Animals were injected with 10 μ Ci of ^{125}I-labelled BSA and either exposed to the NMRI field for 1 hr, or exposed to an audio recording of the NMRI procedure, matched for spectral quality and intensity. After 1 hr a blood sample was taken; the animal was perfused with saline; the brain was harvested; and blood and brain samples were counted. The ratio (CPM g^{-1} brain tissue)/(CPM g^{-1} blood) was then determined for the cerebral hemispheres and for the cerebellum. We found that for both cerebrum and cerebellum there was no significant ($p<.05$) difference between NMRI-exposed and sham-exposed animals, either for animals that had not been handled before the experiments (n=8), or animals that were exposed to handling procedures for 2 weeks prior to the experiments (n=16). Previous studies using very sensitive histofluorescence techniques and a total dose of 20 mg of the non-permanent dye Evans' blue (EB), which is bound to albumin in blood, indicated that EB only permeated the cerebral vasculature to a distance of a few cell diameters in NMRI fields. We found that 5 mg of EB did not change ^{125}I-BSA permeation in NMRI fields. Studies at 20 mg are planned. This work is supported by the Department of Energy, Office of Health and Energy Research, under contract DE-AC-3-76SF00098.

E-2-3 **NUCLEAR MAGNETIC RESONANCE IMAGING (NMRI) FIELDS ALTER CALCIUM METABOLISM IN RAT THYMIC LYMPHOCYTES.** [1]Stephen M. Ross, [1]Jan Walleczek, [1]Robert P. Liburdy, Mark S. Roos and Thomas F. Budinger. [1]Bioelectromagnetics Research Facility, Research Medicine Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94710.

We have exposed rat thymocytes to typical NMRI fields both in the presence and absence of the lymphocyte mitogen, Con-A. The cells were obtained from two groups of Sprague-Dawley rats: Group I: 2 animals weighing 250 g (8 wk), and Group II: 2 animals weighing 450 g (14 wk). Net Ca^{2+} transport was quantitated by means of ^{45}Ca uptake. NMRI fields were typical of multi-slice, multi-echo imaging sequences: static, 2.3 T; switched gradient, B_{peak}=1 mT and dB/dt = 1 T/s; RF, pulsed 64 μT, 100 MHz carrier. Cells from Group I animals responded to Con-A with a large increase in net calcium transport, while cells derived from Group II animals responded only weakly (Table 1). Importantly, cells from Group II, but not Group I, responded to the NMRI field in the presence of Con-A.

Table 1. Animal Group	% Change due to 10 µg/ml Con-A	% Change due to NMRI in the Presence of 10 µg/ml Con-A
I	+ 264.4% p=.002	+ 5.3% p=.587
II	+ 20.3% p=.169	+ 49.9% p=.002

In the absence of Con-A, NMRI exposure caused ^{45}Ca transport to increase 33% in Group I cells, and 26% in Group II cells (average change: 29%, p=.033). The above results indicate 1) that NMRI fields can significantly influence calcium transport and 2) that the effect of these fields is dependent on the degree of mitogen activation. This work is supported by the Department of Energy, Office of Health & Energy Research, under contract DE-AC03-76SF00098. J.W. is supported by the Deutsche Forschungsgemeinschaft (WA680/1-1).

E-2-4 **TIME-VARYING MAGNETIC FIELDS INCREASE CYTOSOLIC FREE Ca^{2+} IN HL60 CELLS.** Jeffrey J.L. Carson, Frank S. Prato*, Dick J. Drost*, Leo D. Diesbourg, and S. Jeffrey Dixon*. The Lawson Research Institute and the Department of Nuclear Medicine, St. Joseph's Health Centre; Division of Oral Biology, University of Western Ontario; London, Ontario, N6A 4V2.

Electromagnetic fields have been reported to cause a variety of biological effects. It has been hypothesized that many of these phenomena are mediated by a primary effect on the concentration of cytosolic free calcium ($[Ca^{2+}]_i$). We investigated the effects of exposure to electromagnetic fields on $[Ca^{2+}]_i$ in HL60 cells using the Ca^{2+}-sensitive fluorescent indicator indo-1. Indo-1-loaded cell samples were exposed to a radiofrequency electromagnetic field, a static magnetic field and a time-varying magnetic field, which were generated by a magnetic resonance imaging (MRI) unit. Spectral analysis of the time-varying magnetic field revealed frequency components of approximately 0.1 mT in the 0 to 100 Hz range, which was followed by a roll off to less than 0.01 mT at 300 Hz. We found that a 23 min exposure to all three fields in combination, induced a significant increase in $[Ca^{2+}]_i$ of 31 +/- 8 nM (mean +/- SEM, $p < 0.01$, $n = 13$) from a basal level of 121 +/- 8nM. As well, cells exposed to only the time-varying magnetic field had a mean $[Ca^{2+}]_i$, which was 34 +/- 10 nM ($p < 0.01$, $n = 11$) higher than parallel control samples. Separate exposure to the radiofrequency (6.25 MHz) or static field (0.15 T) had no detectable effects. These results demonstrate that time-varying magnetic fields alter $[Ca^{2+}]_i$ and suggest that at least some of the reported biological effects of time-varying magnetic fields may arise from elevation of $[Ca^{2+}]_i$.

SESSION E-3:	CALCIUM CHANGES
Moderators:	Jerome Beers and Asher Sheppard

E-3-1 **CALCIUM ION EXCHANGE IN RAT BRAIN SLICES DURING EXPOSURE TO WEAK ELF ELECTRIC FIELD.** Richard D. Saunders, Christine I. Kowalczuk and John B. O'Hagan. National Radiological Protection Board, Chilton, Didcot, Oxon, United Kingdom.

Slices of rat cerebral hemisphere tissue, 350 μm thick, were cut in cold, oxygenated saline (NaCl 124 mM, KCl 5 mM, $CaCl_2$ 0.75 mM, $NaHCO_3$ 26 mM, KH_2PO_4 1.2 mM, $MgSO_4$ 1.3 mM, glucose, 10 mM) using a vibrating-blade tissue slicer (J.G.R. Jefferys, 1981. J.Physiol. 324, 2P). In any one experiment, 5 slices per cerebral hemisphere were incubated at 37°C for 30 min in individual glass tubes with 5 ml of continuously oxygenated (95% O_2:5% CO_2) saline containing 3.7 x 10^4 Bq ml^{-1} (1 μCi/ml) $^{45}Ca^{2+}$. The slices were then washed in saline and placed in 5 ml $^{45}Ca^{2+}$-free, continuously oxygenated saline at 37°C. The slices were exposed or sham-exposed between 2 vertical metal plates, approximately 30 cm apart, for 60 min to a weak, sinusoidal, ELF electric field at a frequency of 5, 15, 30, 50 or 100 Hz and a field strength of 5, 10, 50 or 100 V m^{-1}. The static geomagnetic field component orthogonal to the applied ELF electric fields was 30.8 uT; additional exposures and sham-exposures were carried out at 21 Hz, the approximate cyclotron resonance frequency for unhydrated $^{45}Ca^{2+}$ ions. A 4-position switch with the on/off positions coded allowed all treatments to be carried out "blind". The concentration of $^{45}Ca^{2+}$ was assessed at intervals during treatment and was used to derive the rate of efflux of $^{45}Ca^{2+}$; the data for individual brain slices were fitted to a 2 component exponential decay curve. The conditions of exposure have been decoded, the data are being analysed and will be presented at the meeting.

E-3-2 **COMBINED DC/AC MAGNETIC FIELDS ALTER CA^2+-METABOLISM IN ACTIVATED RAT THYMIC LYMPHOCYTES.** Jan Walleczek and Robert P. Liburdy. Bioelectomagnetics Research Facility, Research Medicine Division, Lawrence Berkeley Laboratory, University of California, Berkeley CA 94720.

Several reports suggest that biological responses to electromagnetic fields may be DC magnetic field dependent (1-3). We used an in vitro T-cell system to determine if calcium transport is altered by combined DC/AC vs. AC magnetic fields. Parallel combination of a 21.0 +/- 0.3 uT_{rms} DC and a 14.3 Hz sinusoidal 21.0 +/- 0.3 uT_{rms} magnetic field stimulated transport by 60% ($n=6$, $p<0.01$) in mitogen activated T-cells (60 min, 1 mM $CaCl_2$, 37°C); no alteration was detected using the AC field alone. In contrast, quiescent, nonactivated lymphocytes did not respond to the AC/DC field combination. Careful dosimetry and testing for a dependence on

amplitude and frequency are now required to provide evidence supporting a specific mode of interaction. Supported by the Department of Energy, Office of Energy Storage and Distribution, under contract DE-AC03-76SF000098. J.W. is supported by the Deutsche Forschungsgemeinschaft (WA 680/1-1).
1. C.F. Blackman, et al. (1985) Bioelectromagnetics 6, 327
2. A.R. Liboff and B.R. McLeod (1988) Bioelectromagnetics 9, 39
3. C. Polk (1989) 11th Ann. Meeting of the BEMS, June 18-22, Tucson, AZ

E-3-3 **THE INFLUENCE OF TEMPERATURE DURING THE FIELD-INDUCED ALTERATION OF CALCIUM RELEASE FROM BRAIN TISSUE, IN VITRO.** C.F. Blackman, S.G. Benane*, D.E. House*. US Environmental Protection Agency, Health Effects Research Laboratory, Research Triangle Park, NC 27711.

The release of calcium ions from in vitro preparations of chicken brain-tissue has been used by several investigators to demonstrate the interaction of electric and magnetic (EM) fields with biological systems. For exposures with radiofrequency radiation amplitude modulated at extremely low frequencies (ELF), the observations have all been of field-induced enhancement of the calcium release. In contrast, when only ELF EM fields are employed, the release of calcium ions has been reported by one research group to be inhibited and by another group, enhanced. The results in this report demonstrate that either observation, or a null result, is possible under exposure of 16-Hz sinusoidal EM fields, at 14.1 Vrms/m (in air), and 64 nTesla-rms, depending upon the thermal condition of the samples prior to and during exposure. When the sample temperature is ascending during the 20 minute exposure to a final temperature of either 35, 36 or 37 but not 38 or 39°C, enhanced release is observed; when stable during exposure (i.e., within +/- 0.3°C) to a final temperature of 36 or 37 but not 35 or 38°C, the release is reduced; and when descending to any final temperature between 35 to 38°C, a null result occurs. Thus, temperature "windows" are shown to be another critical aspect of this phenomenon. This finding may reconcile the disagreement in the direction of the field-induced response and explain the reason the experimental result is so difficult to replicate. This result also provides a clue to the underlying basis for the field-induced phenomenon.

This is an abstract of a proposed presentation and does not necessarily reflect EPA policy.

E-3-4 **MODULATION OF CALCIUM UPTAKE BY CONCANAVALIN A AND OUABAIN IN NORMAL AND LEUKEMIC T-LYMPHOCYTES EXPOSED TO MAGNETIC FIELDS UNDER CALCIUM CYCLOTRON RESONANCE CONDITIONS.** Daniel B. Lyle, Xinghua Wang, Robert D. Ayotte, Asher R. Sheppard, and W. Ross Adey. Jerry L. Pettis Memorial Veterans' Hospital, Loma Linda, CA 92357.

We have initiated experiments to investigate the mechanism(s) whereby a weak, alternating magnetic field meeting the conditions for calcium ion cyclotron resonance (16.5 uT; 11.1 Hz for Ca^{45}) for the horizontal component (16.5 uT) of the local static magnetic field influence calcium uptake in lymphocytes. The sinusoidal field was generated by a Helmholtz coil pair. Test cultures were compared to a sham culture located in the same incubator (37 +/- 0.5°C) in a mu-metal box 120 cm from the Helmholtz coils. Incorporation of calcium was determined by incubating cells with Ca^{45} for different periods of time in T-25 flasks gassed with 5% CO_2 then washing the cells twice and determinating radiation by scintillation. Over a 24-hour period, 15 ug/ml concanavalin A increased Ca^{45} incorporation in normal rat spleen lymphocytes three-fold. Over various periods of time, concentrations of ouabain from 0.01 mM to 1.0 mM were seen to also increase Ca^{45} incorporation up to three-fold. Preliminary results suggest no effect by the field on the concanavalin A effect, but a blockage of the ouabain effect. This suggests that the field might not be affecting calcium channels directly, but may be increasing calcium by indirect mechanisms. (Supported by the U.S. Dept. of Energy Office of Energy Storage and Distribution, the Dreyfus Medical Foundation, and the General Motors Medical Research Institute.)

SESSION F-1: **NERVOUS SYSTEM I**
Moderators: Richard Lovely and Walter Rogers

F-1-1 **FREQUENCY- AND CALCIUM-DEPENDENCE OF ELECTRIC FIELD EFFECTS ON THE RESISTANCE AND POTENTIAL OF APLYSIA NEURONS.** A.R. Sheppard, R.G. Villanueva*, and W.R. Adey. J.L. Pettis Memorial Veterans Hospital and Loma Linda University, Loma Linda, CA 92357.

We made intracellular recordings from Aplysia neurons in vitro to look for changes in membrane potential (V_m) and cell resistance (R) during and after exposure to 60-Hz electric fields (1 V/m_{rms} for 30 min). Changes in R and V_m reflect changes in the overall open/closed status of thousands of channels. Previously, we saw field-related changes during 10-Hz fields in normal artificial seawater (ASW) (12 mM Ca^{2+}, 48 mM Mg^{2+}) and a consistent decrease in R during tests in a low-Ca^{2+} ASW

(1 mM Ca^{2+}, 59 mM Mg^{2+}) that attenuated synaptic activity and other Ca^{2+}-dependent processes. As before, temperature was constant at ~21°C; data for R (by hyperpolarizing current clamps) and V_m were taken at 30 s intervals. Preliminary analysis for 11 60-Hz-exposed cells (and 9 shams) showed no reliable field effects on V_m or R. Over the exposure, V_m shifts averaged -0.9 +/- 3.4 mV; -0.3 +/- 4.6 mV (ASW; lo-Ca^{2+}-ASW, respectively). Data for R were similar: shifts averaged 0.3 +/- 0.7 Mohm; -0.1 +/- 0.5 Mohm. Disregarding magnitudes, R declined noticeably in 57% of the low-Ca^{2+} tests, unlike the results with 10-Hz, where R fell in 91% of such tests. Our 10-Hz results showed R and V_m were affected even without synaptic coupling between cells while the 10- and 60-Hz data showed frequency dependence. (Supported by US Department of Energy, Office of Energy Storage and Distribution (DE-A101-85CE76260) and General Motors Research Laboratories.)

F-1-2 **INHIBITORY EFFECTS OF EXPOSURE TO 60 HZ MAGNETIC FIELDS AND CLINICAL MAGNETIC RESONANCE IMAGING PROCEDURES ON OPIATE-INDUCED 'ANALGESIA' IN A LAND SNAIL.** M. Kavaliers*, F.S. Prato*, J.R.H. Frappier*, and K.-P. Ossenkopp*. Dept. Nuclear Medicine, St. Joseph's Health Care Centre of London, Div. Oral Biology, Fac. Dentistry and Dept. Psychology, University of Western Ontario, London, Ontario, Canada (Sponsor, D. Hjeresen, Los Alamos National Laboratory, Los Alamos, NM).

There is accumulating evidence that magnetic fields can affect opioid mediated functions. Opioid systems have been implicated in the mediation of the thermal avoidance behaviors ("nociceptive" responses) of the land snail, Cepaea nemoralis. Administration of the opiate agonist, morphine, to Cepaea elicits an increase in the latency of the avoidance response to a warmed surface that is indicative of 'analgesia' and similar to the opiate-mediated analgesia observed in rodents. In the present study we examined the effects of (i) various durations (0.50, 2.0 and 24 h) of exposure to weak (1.0 gauss, rms) 60 Hz magnetic fields, and (ii) a clinical magnetic resonance imaging (MRI) procedure and associated time-varying magnetic field (23.2 min, duration) on morphine (10 mg/kg, 2.0 ul) induced analgesia in Cepaea. Exposure to the 60 Hz fields significantly reduced analgesia, with the degree of attenuation being related to the duration of exposure. The shorter exposure to the MRI procedure also markedly reduced analgesia, with the time-varying magnetic field associated with the MRI procedure having by itself a significant inhibitory effect. These findings indicate that the opiate-mediated analgesic responses of the snail, Cepaea, are sensitive to 60 Hz magnetic fields and magnetic fields associated with MRI procedures in a manner similar to that reported for rodents.

F-1-3 **ASSESSMENT OF RAT'S BEHAVIOR IN A RADIAL ARM MAZE DURING EXPOSURE TO MAGNETIC FIELDS.** J.A. Creim, R.H. Lovely, D.L. Miller and L.E. Anderson. Battelle, Pacific Northwest Laboratory, Richland, WA. 99352.

This study is to determine if the in vitro efflux of calcium ions from animal cortex, that results from exposure to ELF fields, is physiologically significant in vivo. Long term, potentiation (LTP) and memory in the rat, when performing in a radial arm maze (RAM), have been shown to be causally dependent on movement of free calcium ions in animal cortex. Both effects rely on glutamate binding to the NMDA receptor which inturn causes conformational changes in the Ca^{2+} ion ionophore. The effects and the resulting Ca^{2+} ion current are necessary conditions for LTP and RAM memory in rats. We are assessing RAM performance in rats while they are exposed to ELF and dc magnetic fields (MFs). The exposure system produces uniform (+/-5% ELF and dc MFs (vertically and horizontally) within the RAM. The field strengths are a dc MF of 2.6×10^{-5} T (0.26 G) in combination with a 60-Hz MF of 5×10^{-5} Trms (0.5 G). Briefly, the RAM consists of 8 equal length arms radiating out from a central arena with a door at the entrance and a food cup at the end of each arm. Twenty four male Sprague Dawley rats were food deprived to 80%-85% of their free feeding weight and then individually assessed in the RAM daily. Twelve rats were exposed during the RAM assessments, while the other 12 rats were sham-exposed. Presently the study is ongoing, but preliminary analysis of errors/group using a repeated measures ANOVA approach significance ($p<0.086$), with the exposed group making more errors. This data, when combined with results of a similar previous study, indicate a significant increase in errors made by the exposed groups ($p<.015$). Work supported by DOE/OESD under Contract DE-AC06-76RLO-1830.

F-1-4 **PRE-EXPOSURE STIMULATION OF NERVE REGENERATION: DEPENDENCE UPON MAGNETIC FIELD INTENSITY.** B.F. Sisken, M. Kanje*, G. Lundborg* and W. Kurtz*. Center for Biomedical Engineering and Dept. of Anatomy, Univ. of Kentucky, Lexington, KY 40506; Dept. of Zoophysiology and Dept. Orthop. Surg., Univ. of Lund, S-223 62 Lund, Sweden and Bietic Research, Inc., Lyndhurst, NJ.

In vitro and in vivo models have been used to test the regenerative influence of non-invasive, low level pulsed electromagnetic fields (PEMF). Exposing rats after a "crush" lesion of the sciatic nerves to a 2 Hz, 0.3 mTesla signal for 4 hours/day for 3, 4 or 6 days resulted in a 22% increase in the regeneration rate relative to control animals with no effect on the initial delay period. When unoperated rats were exposed to PEMF before lesioning exclusively, the same degree of stimulation of nerve regeneration was obtained. Variation in the time of exposure to PEMF (4 hours/day for 7 days or for 1 day) before lesioning resulted in the same degree of

stimulation. When the amplitude of the signal was reduced from 0.3 mTesla to 0.06 mTesla the pre-exposure stimulus response disappeared. These results infer that the magnetic field component plays a role in the enhanced regenerative response obtained in both biological models.

F-1-5 **MODIFICATION BY PEMF OF NEW PROTEINS SYNTHESIZED IN TRANSECTED RAT SCIATIC NERVE.** Betty F. Sisken, Martin Blank and W. Kurtz. *Center for Biomedical Engineering and Dept. of Anatomy and Neurobiology, Univ. of Kentucky, Lexington, KY 40506; Dept. of Physiology, Columbia Univ., New York, NY 10032 and Bietic Research, Inc., Lyndhurst, NJ.

Pulsed electromagnetic fields (PEMF, 0.3 mT, pulsed for 20 msec at a repetition rate of 2 Hz, 4 hrs/day) stimulates regeneration of rat sciatic nerve following a crush (1) or transection (2) injury. Exposure of animals to PEMF before the crush is made also evokes an increased regeneration response (1). To determine the mechanisms underlying the PEMF effects, rat sciatic nerves were transected and reapproximated. Experimental animals were treated with PEMF for 4 hours/day for 5 days, the control animals were not treated. After an interval of two weeks the transected and untransected segment of sciatic nerves from control and PEMF-treated rats were incubated in ^{35}S-methionine in methionine-depleted culture medium for 4 hours at 37°C. The nerve sediments were analyzed by Protein Databases Inc., NY on 2D gels. The new polypeptides found were derived primarily from Schwann cells and fibroblasts found in the isolated nerves. Analyses of nerves from control and experimental animals indicated: a) the presence or absence of new polypeptides, and b) differences in distribution of polypeptides based on molecular weight class as a function of transection and PEMF treatment.
(1) Sisken et al., Brain Res. 485, 1989 (2) Zienowicz et al (submitted).

F-1-6 **RFR EVOKED POTENTIALS IN THE FROG EIGHTH NERVE.** Ronald L. Seaman. Department of Biomedical Engineering, Louisiana Tech University, Ruston, LA 71272.

To test responsiveness of the frog inner ear to RFR pulses, potentials were recorded in anesthetized bullfrogs (Rana catesbeiana) using nonperturbing electrodes implanted medially and laterally to the left eighth nerve. Thirty-five μs RFR pulses at 2450 MHz were delivered to the inner ear with the open end of a 0.085-inch semi-rigid coaxial cable inserted through the left tympanum. Responses were obtained for pulse SARs of 26-348 mW/g (0.9-12.2 μJ/g). Responses to 200 RFR pulses applied every 1.2-1.4 s were averaged to obtain an evoked response for each RFR condition. An initial negative-positive wave with latency-to-peak of 2.7-3.4 ms represented the eighth-nerve response. For this biphasic wave, amplitude increased and latency decreased with increased pulse intensity, typical of sensory systems. In each frog, the initial wave had the general shape and amplitude of responses to ipsilateral airborne acoustic stimuli while the latency was 0.3-0.5 ms shorter. Later,

multiple positive peaks in the response differed from the one or two negative peaks seen consistently in acoustic responses. The responses indicate that RFR can stimulate non-mammalian sensory systems. Action on one or more of the eight sensory epithelia of the frog inner ear is indicated. Primary candidates are auditory and seismic receptors, perhaps excited by means of acoustic energy generated by RFR absorption.

Sponsored by AFOSR/AFSC Contract F49620-88-C-0053.

SESSION F-2: **NERVOUS SYSTEM II**
Moderators: Peter Semm, Ronald Seaman and John D'Andrea

F-2-2 **CRITICAL DURATIONS OF PULSE MICROWAVE EXPOSURES THAT EVOKE BODY MOVEMENTS.** H. Wachtel, D. Brown, H. Bassen. University of Colorado, Boulder, CO 80309. ERC Bioservices Corp., Gaithersburg, MD 20879. Walter Reed Army Inst. of Research, Washington, DC 20307-5100.

We have demonstrated that brief microwave (1250 MHz) exposures of mice leading to mid-brain Specific Absorptions (SA) on the order of 0.5 J/g can evoke multiphasic body movements, particularly in the interval from 0.1 to 1.0 seconds following the exposure. These experiments were carried out in a waveguide exposure system previously described (Bassen et al, 1988). We found that bursts of narrow pulses (10 microsec duration, 80 pps, for 12.5 to 100 msec) were only slightly more effective than were single wide pulses (12.5 to 100 msec duration) for the same SA values. These results suggest that the critical "brief" time period for delivering sufficient microwave energy to evoke such responses is not in the microsecond, or even the millisecond range but may extend to at least several seconds. In order to test this hypothesis and to determine the limit of "brief" exposure time (beyond which the evoked movement diminishes for a given SA) we have developed a system that operates over a wider range of exposure times. With this system bursts of narrow pulses, as well as single wide pulses, leading to a mid-brain SA of 0.5 J/g can be applied over time periods which are sequentially doubled until no response is evoked. At that point the SA is raised (to 1.0 J/g) and further extension of the exposure period is explored (up to 360 secs). This system allows us to determine at what point the specific absorption rate (SAR) becomes the salient parameter rather than the SA—i.e. what the limit for "brief" exposure time is.
This work was performed under contract DAMD-17-89-C-9021 from the U.S. Army Medical R & D Command.

F-2-3 **SENSITIVITY TO SMALL MAGNETIC VARIATIONS BY THE TRIGEMINAL SYSTEM OF THE BOBOLINK (DOLICHONYX ORYZIVORUS).** P. Semm and R.C. Beason*. Dept. of Zoology, University of Frankfurt, Siesmayerstr. 70, 6000 Frankfurt, FRG. *Dept. of Biology, State University of New York, Geneseo, NY 14454.

Electrophysiological recordings from the ophthalmic nerve and the trigeminal ganglion of the bobolink indicate the presence of a few units (15%) that respond to changes in the earth's magnetic field. The most common response was an increase in the rate of spontaneous activity. The most sensitive units responded to changes of 200 nT (<0.5% of the earth's total field). Other responses included reactions to a 0.5 Hz sinusoidal variation and to a hand-held bar magnet. Because of the sensitivity, it is hypothesized that these responses may be involved in detecting the magnetic map used in navigation. One possible transducer substance that could account for such a sensitivity is magnetite which has been previously reported in the upper beak area of the bobolink.

SESSION F-3: **ENDOCRINE**
Moderators: Peter Semm and Ronald Seaman

F-3-1 **AN EXPERIMENTAL STUDY OF MELATONIN AND PUBERTY IN FEMALE LAMBS RAISED BENEATH A 500-kV TRANSMISSION LINE.** J. Lee, F. Stormshak*[1], J. Thompson*[1] D. Hess*[2] and R. Forbes*[3]. Bonneville Power Administration, Portland, OR 97208; Oregon State University[1] Corvallis, OR 97331; Oregon Regional Primate Research Center[2] Beaverton, OR 97006; Portland State University[3] Portland, OR 97207.

The purpose of this research project is to determine if a specific effect of electric and magnetic fields found in laboratory animals also occurs in sheep under natural environmental conditions. Past research has found that 60-Hz electric fields, and d-c magnetic fields can significantly depress the normally high nocturnal levels of the pineal hormone melatonin. Melatonin mediates the reproductive response to changes in photoperiod in seasonal breeders such as sheep. This experimental study is designed to test the following hypothesis: The electrical environment of a 500-kV transmission line causes a depression in nocturnal melatonin in chronically exposed female lambs. This mimics effects of pinealectomy or long-day photoperiods, thus delaying onset of puberty. Ten female lambs will be penned beneath a 500-kV line for 10 months and exposed to 60-Hz fields averaging 8 kV/m and 50 mG. Ten lambs will be maintained in a control pen with fields below 10 V/m and 1 mG. Exposure begins in April 1990. Melatonin levels will be sampled at 0.5-3 hour intervals over seven 48-hour periods. Levels of progesterone and cortisol will

also be measured, and data will be collected on wool growth and behavior. The study is sponsored by the Bonneville Power Administration and five other utility organizations.

F-3-2 **EFFECT OF 60-Hz ELECTRIC FIELDS ON MELATONIN PRODUCTION IN THE RAT: CORRELATIONS BETWEEN PINEAL, SERUM AND URINE.** L.B. Sasser, J.E. Morris, and L.E. Anderson. Battelle, Pacific Northwest Laboratory, Richland, WA 99352.

We have previously shown that 60-Hz electric fields significantly decrease the normally high nocturnal melatonin concentration of the rat pineal gland. Studies of pineal function would be enhanced if methods were available for non-invasive evaluation of the melatonin response to ELF. Urinary 6-OH melatonin sulfate (6-HMS) is a potential alternative for assessing pineal function at an stage of exposure. The objective of this study was to evaluate and correlate pineal and serum melatonin, and urinary 6-HMS concentrations of rats exposed to electric fields. Seventy-two 8-week old Sprague-Dawley rats were exposed or sham-exposed to 60-Hz electric fields for 20 hrs/day for 30 days. Daytime and nighttime urine samples of 10 rats from each group were collected three times each week throughout the study and were analyzed for 6-HMS. At the end of exposure, 16 rats from each exposure group were sacrificed during midday and 16 were sacrificed at midnight. Serum, pineal, and Harderian glands were collected, frozen and analyzed for melatonin. Correlative analysis of pineal and serum melatonin and urinary 6-HMS will be presented to demonstrate the potential of urinary measurements as a predictor of pineal function and melatonin production in electric field studies. Supported by the U.S. Department of Energy under Contract DOE-AC06-76RLO 1830.

F-3-3 **BIOCHEMICAL AND HORMONAL EVALUATION OF PINEAL GLAND IN VITRO.** Frederick C. Leung, Chris A. Poindexter, Douglas L. Miller and Larry E. Anderson. Battelle, Pacific Northwest Laboratories, Richland, WA 99352

The objective of this project is to examine the effects of electric (E) and/or magnetic (B) fields on melatonin metabolism in pineal glands in vitro. Chicken pineals are cultured in a modified laboratory incubator which contains a regulated light source for modulation of the light/dark cycle (12:12 L/D). The pineals from 2-6 week old chickens are maintained under 95% 0_2, 5% CO_2 in either a static or perfusion organ culture system. Melatonin produced by the cultured glands and secreted into the culture medium is measured by radioimmunoassay using I-125 labeled melatonin. The experimental protocol is as follows: In the static system, chicken pineal glands are pre-incubated overnight, followed by collection of medium samples every 4 hours for three days. In the perfusion system, 10 pineal glands are maintained in a chamber that has continuous flow through medium. Samples are collected into a

fraction collector. In both culture systems, all medium samples are frozen immediately after collection and kept at -20°C until assay. Preliminary results indicate that chicken pineal glands do maintain a strong rhythm of melatonin cyclicity in vitro in both culture systems. Thus, in vitro organ culture of chicken pineal glands will allow us to examine the possible direct effects of E and/or B fields on melatonin metabolism in pineal gland. Research funded under Electric Power Research Institute contract RP2965-10.

F-3-4 **INTERMITTENT EXPOSURE TO STEADY MAGNETIC FIELDS: EFFECTS ON NOCTURNAL PINEAL MELATONIN AND SEROTONIN IN RATS.** Alexander Lerchl, Keico O. Nonaka, and Russel J. Reiter. Department of Cellular and Structural Biology, University of Texas Health Science Center, 7703 Floyd Curl Drive, San Antonio, TX 78284.

The aim of this study was to ascertain whether the exposure to a steady, intermittent magnetic field influences nighttime pineal serotonin (5-H) metabolism. 16 adult, male Sprague Dawley rats (BW 120-130g) were kept under a 14 hours white light / 10 hours dim red light cycle (white lights on at 07.00 hr) for one week. The animals were divided into two groups and each was transferred to a plastic cage and covered with an identical one upside down. One pair of cages was placed between a pair of Helmholtz coils (d=r=0.5m, n=300). The axes of the coils were aligned in a horizontal north south direction. The control animals were kept in the same room, away from the coils. 3.5 hours after the lights off, a DC power supply was turned on for one hour, resulting in an inversion of the magnetic field's direction inside the cages at approx. 0.5 Gauss. The power supply was turned off 6 times during the one hour exposure at regular intervals of 5 min each. After exposure, the animals were decapitated in an alternating order. The pineals were removed, frozen on dry-ice and stored at -60°C. N-acetyltransferase (NAT) and hydroxyindole-O-methyltransferase (HIOMT) were determined radioenzymatically, and melatonin was measured by radioimmunoassay. Levels of 5-HT and 5-hydroxy indole acetic acid (5-HIAA) were estimated by HPLC with electrochemical detection. The exposure to the intermittent field resulted in a significant ($p<0.025$) decrease of NAT activity, whereas the HIOMT activity was not affected. Furthermore, the levels of 5-HT and 5-HIAA were found to be increased by the magnetic field ($p<0.01$, and $p<0.05$, respectively). However, both the amount of melatonin in the pineal gland as well as the serum melatonin levels were not altered. The results indicate that under the described conditions the synthesis and metabolism of serotonin in the pineal may be affected by the exposure to a magnetic field. Supported by NSF grant # DCB8711241. A.L. is currently supported by a NATO fellowship.

SESSION F-4: **INSTRUMENTATION II**
Moderators: William Joines and Edwin Mantiply

F-4-1 **MEASUREMENTS OF BROADBAND ELECTRIC AND MAGNETIC FIELDS EMITTED BY PULSED MICROWAVE SOURCES.** Kari Jokela. Finnish Centre for Radiation and Nuclear Safety, Helsinki, Finland.

Pulsed electric and magnetic fields were measured in both time and frequency domains at a distance of 50 cm from the pulse modulator of seven microwave sources. The measurement antennas consisted of two electrically shielded loop antennas (2 kHz - 20 MHz) and one fiber optic coupled active dipole antenna (50 Hz - 1.3 MHz). The induced voltage at antenna terminals was measured with a digital oscilloscope and the recorded waveforms were transformed into the frequency domain with Fast Fourier Transform (FFT). The maximal measured linear (lin) and root-mean-square (rms) values of magnetic flux density were 7.9 μT and 0.32 μT respectively, at a frequency range from 10 kHz to 2 MHz. Linear values differ less than +/- 50 percent from instantaneous peak values. The corresponding values or the time derivative of magnetic flux density and electric field strength were 11 T/s (lin), 0.26 T/s (rms), 425 V/m (lin) and 87 V/m (rms). The measured rms values are considerably lower than the comparable exposure standard values 59.2 T/s (DIN VDE), 12.6 T/s (IRPA), 2 μT (ACGIH), 1500 V/m (DIN VDE) and 614 V/m (IRPA). The instantaneous peak values were close to the exposure limits, if they are defined as linear sum of relative exposure (ratio of field strength to field strength limit for each harmonics. Moreover, the estimated maximal peak current density induced in a human body in the measurement position exceeded about 300 times the maximal current density estimated for VDU operators. For rms values this ratio was about 40. The electric and magnetic field near pulse modulators contain more high frequency components than the fields near video display units.

F-4-2 **AN EMP-INDUCED CURRENT MEASUREMENT DEVICE.** Jin-Yuan Chen and Om P. Gandhi. Department of Electrical Engineering, University of Utah, Salt Lake City, Utah 84112.

In a companion paper we have described the use of the finite-difference time-domain numerical technique to calculate induced currents in the various parts of the human body. Highly damped nearly oscillatory currents have been calculated for the various sections of the body with a peak of current occurring 10-12 ns after the onset of the pulse. The entire duration of the induced current is typically less than 100-200 nsec with bulk of the current in the first 30-50 nsec of the EMP. We have designed and fabricated a device to measure the current passing through the feet of a person for induced currents of tens of nanosecond duration. This digital display meter using a sample and hold circuit is capable of displaying the following

quantities: a. The peak current induced in the body, b. the integrate charge $\int I dt$ passing through the body.

F-4-3 **A WAVEGUIDE EXPOSURE SYSTEM INCORPORATING A NON-METALLIC CYLINDRICAL STABILIMETER FOR STUDYING MICROWAVE EVOKED OR MODIFIED BODY MOVEMENTS.** Dolores A. Beblo*, and Ronald L. Seaman. ERC BioServices Corporation, Gaithersburg, Maryland 20879.

Researchers have reported that pulsed microwaves both evoke body movements and modify the startle responses of rodents. In order to study this phenomena a wave guide exposure system capable of producing an SAR up to 8 MW/kg and associated SA of 80 J/kg at 1.25 GHz in the head of rats has been developed. The system also incorporates provisions for using acoustic and tactile stimuli. The exposure chamber which consists of WR650 waveguide focuses microwave energy in the head and neck region using a hybrid tee with adjustable shorts to enhance load matching. Rats weighing from 250g to 300g are positioned inside a cylindrical holder as an integral part of the stabilimeter which is made of all non-metallic parts. The stabilimeter incorporates a moving platform supported by sections of tubing which provide spring action. Motion is detected using piezoelectric film. The stabilimeter is inserted partially into the wave guide broad wall three-quarters of a wavelength from a short termination. The system is controlled by a personal computer which enables sequencing and amplitude of the stimuli and detection of body movement. This work is supported by contract number DAMD1789-C-0921 from the Walter Reed Army Institute of Research, US Army Medical R&D Command.

F-4-4 **CALIBRATION OF RF FIELD SURVEY INSTRUMENTS IN THE PRESENCE OF SEVERAL FREQUENCIES.** Kjell Hansson Mild[1], Lennart Olsson*[2], and Andre Berglund*[1]. [1]Natl. Inst. Occup. Health, Umea, and [2]Swedish Telecom Radio, Sundsvall Sweden.

Work on broadcast towers are often performed while the station is broadcasting at full power. Maintenance personnel may then be exposed to large RF fields and it is necessary to measure the field strengths so that the exposure do not reach hazardous levels. The instrumentation used for such surveys usually have a diode type sensor for the RF field, and, hence, it may be sensitive to the peak value rather than indicating an rms-value. This does not cause a problem when measurements are taken on a single frequency, but when several frequencies are present the reading will be too high. The Swedish radio stations usually broadcast four different sound programmes at the same time but on four different frequencies in the FM-band 88-108 MHz and on the same antenna. In the present study we have investigated the performance of some field survey instruments, RF voltmeters and powermeters in the presence of up to four different FM frequencies at the same time. The amplitude

of the various signals has also been varied. We find that with two frequencies present at equal amplitude the Holaday HI-3002 E-field probe gives a too high reading with a factor of 1.4, as compared with a thermal sensing instrument. The corresponding values with 3 and 4 frequencies present are 1.6 and 1.8, respectively. Diode based RF voltmeters and power meters gave similar erroneous readings. The Holaday HI-3002 H-field probe was not as sensitive to several frequencies. The readings for 2,3, and 4 frequencies present gave too high readings with the factors 1.2, 1.3 and 1.4, respectively.

F-4-5 **SMALL INTEGRATING METER FOR POWER-FREQUENCY MAGNETIC FIELD EXPOSURE ASSESSMENT.** W.T. Kaune, J.C. Niple, and J.M. Silva. Enertech Consultants, Campbell, CA; L.E. Zaffanella, High Voltage Transmission Research Center, Lenox, MA.

We have previously described an Average Magnetic Field Exposure Meter (AMEX) that measures the time integral of one axis of magnetic flux density. To deal with the single-axis sensitivity of this meter, which is a significant limitation in many environments, we have developed a new meter (AMEX3) that measures all three axes of magnetic flux density and electronically combines these data into a single estimate of cumulative exposure to the rms total flux density. The AMEX3, weighing about 115 g, is housed in a rugged 2.7-cm x 5.1-cm x 10.2-cm plastic box. Two jacks are provided for measuring the battery voltage and for reading cumulative exposure data from the built-in electrochemical storage cell. The bandwidth and dynamic range of the instrument extend from 40 to 800 Hz and from well below 1 mG to about 125 mG, respectively. Battery life is sufficient for continuous measurements over a minimum period of 14 d. The AMEX3 was tested by simultaneously using it and EMDEX meters to measure the exposures of 30 utility workers during 8-h workdays: the correlation between these two measures was 0.97. A careful analysis of AMEX3 errors is now underway. Pilot tests indicate individuals ranging in age from 18 months through adulthood will accept and wear the AMEX3 for 24-h periods. This work is supported by the Electric Power Research Institute under contract RP 799-16.

F-4-6 **AUTOMATED BLOOD SAMPLING SYSTEM FOR USE WITH TETHERED BABOONS.** Jeffrey H. Lucas*, Walter R. Rogers, John L. Orr and H. Dwaine Smith*. Southwest Research Institute, San Antonio, TX 78228-0510 and Brian C. Mikiten*, BCM Designs, San Antonio, TX 78231.

Southwest Research Institute has developed an automated blood sampling system for use with tethered baboons (Papio cynocephalus). The system will be used to collect blood samples for analysis of hormones. The system makes it possible to draw blood samples during exposures to high-intensity, 60-Hz electric fields without a human present. A unique swivel mechanism at the end of the tether minimizes the formation of blood clots, yet allows the baboon to freely move inside

its cage. The hardware and software are designed for "fail-safe" operation. In the automated mode, saline is infused at a rate of 0.5 ml/minute until a sample cycle is initiated. In a sample cycle, the blood is drawn into a storage ring, a sample of undiluted blood is taken from the end of the storage ring near the animal, then the remaining blood is flushed back into the baboon. Use of the storage ring prevents the peristaltic pump rollers from contacting blood and allows return of the blood diluted with saline to the baboon. Return of the saline-diluted blood limits the blood wasted per sample to less than 1 ml. The system is controlled by a Forth-based microcomputer which controls a pump, fraction collector, and two pinch valves. The pinch valves are used so blood only contacts the silicone tubing. This project was sponsored jointly by the United States Department of Energy and the Central Research Institute of the Electric Power Industry of Japan as a part of contract DE-ACO2-RA50219 to Southwest Research Institute.

F-4-7 **A SYSTEM FOR THE EXPOSURE OF SMALL LABORATORY ANIMALS TO A 25-mT 60-Hz ALTERNATING OR TRAVELLING MAGNETIC FIELD.** Wagih Z. Fam and Eva L. Mikhail*. Technical University of Nova Scotia, Halifax, N.S., Canada B3J 2X4.

The system was built as a part of an extensive experimental investigation into the biological effects of 60-Hz magnetic field on small laboratory animals. It consists of three separate rectangular coils mounted on a wooden frame. Each coil is approximately 50 x 30 cm and has 260 turns of A.W.G. #10 wire, a dc resistance of 1.4 ohm, and a weight of 16.65 Kg. When mounted, the separation between any two adjacent coils is 10 cm. Three plastic shelves divide the wooden frame into four compartments; each is capable of accommodating two 20 x 11 8.5 cm plastic cages. Each cage is suitable for housing one male and one female mouse or one nursing mother with its litter. Plastic covers are used for the cages with large number of holes for ventilation and one hole for the drinking water bottle. In order to produce a 60 Hz, 25-mT alternating magnetic field, a current of 13 A was passed in each coil and cooling fans were used to keep the coil temperature to 45°. Due to the large self inductance of the coils, a supply having a voltage of 300 V would have been necessary even if all three coils are connected in parallel. To overcome this problem, the effect of the self and mutual inductances was neutralized by connecting a capacitor in series with each coil, and the magnitude of the capacitance was adjusted until the circuit is very nearly at resonance. This ensured that the current and voltage were in phase and the circuit was operating near unity power factor. The voltage required to drive 13 A in each coil was only 40 V and was obtained from a single-phase variac. All three variacs were mechanically ganged together, and their primaries connected in parallel and supplied from a 115-V, 60-Hz supply. The magnetic field varied between 25-mT near the center of the coils to 27.2-mT near the sides of the coils. If a travelling magnetic field was required, the primaries of the three variacs were connected a 3-phase, Y-connection and supplied from a 3-phase 208-V, 60 Hz supply.

F-4-8 **MONITORING OF ANIMAL EXPOSURE DURING ELF MAGNETIC FIELD STUDIES.** William E. Feero, David C. Robertson, and Robert C. Patterson. Electric Research & Management, Inc., State College, PA 16804.

A monitoring system originally designed to continuously sample the magnetic fields in a building has been incorporated into the data logging and control of an animal exposure system. Beyond typical laboratory ambient monitoring, the system features simultaneous measurement of the magnetic fields at a minimum of two points per exposure and sham modules and the driving current sources of the exposure modules. The field and current measurements are made by sampling one cycle of the driving source frequency of the respective waveforms with a sampling rate of 64 samples per cycle. With this data, the control unit makes a Fast Fourier Transform of each sample point to determine that harmonic content has not risen above a selectable level in either the exposure or sham areas, while certifying that the fundamental frequency is within pre-selected bounds. Under normal conditions, the recording system enters only hourly logs of a complete data set to verify the monitoring system is operational, but if an out-of-range parameter is detected, then logs are recorded at one minute intervals. If any parameter goes outside of a specified range for a specified period, the control unit will alarm and/or call designated phone numbers. Should an external field source appear during an exposure period, built in correlation routines will help to rapidly identify the offending source.

SESSION G-1:	**SYMPOSIUM 3- MECHANISMS OF RESPONSE TO ELECTROMAGNETIC FIELDS IN BONE HEALING JOINT SESSION WITH BIOELECTRICAL REPAIR AND GROWTH SOCIETY (BRAGS)**
Organizers:	Roy Aaron and Charles Polk

G-1-2 **SENSITIVITY OF DEVELOPMENTAL EVENTS IN ENDOCHONDRAL OSSIFICATION TO STIMULATION WITH PEMF.** Deborah McK. Ciombor, and Roy K. Aaron. Department of Biochemistry/Biophysics and The Section of Bioengineering, University of Rhode Island, Kingston, RI 02881.

Endochondral ossification is the basic process in bone repair, embryogenesis, and skeletal growth. Using a model of experimental endochondral ossification we have shown that PEMF increases bone formation and synthesis of extracellular matrix.

Ossicles exposed to PEMF during the phases of cell recruitment and chondrogenesis (d.1-8) have calcium content and trabecular maturation equal to those exposed

for the full developmental sequence. Ossicles exposed during calcification and bone formation (d.9-19) have a significantly lower calcium content and less maturation trabeculae. Further, ossicles exposed during the phase of cell recruitment and proliferation (d.1-3) have subsequent bone formation equal to ossicles exposed throughout the full developmental sequence. The formation of cartilage extracellular matrix can also be stimulated by exposure during selected developmental sequences. Chromatographic analysis has demonstrated the stimulation of normal cartilage molecules by exposure to PEMF. mRNA for proteoglycan core protein and type II collagen was quantitated by Northern hybridization with specific cDNA probes and dot blot analysis. The expression of these genes is affected by PEMF. Stimulation of ossicles during the cellular phase (d. 1-3) produces an equal amount of cartilage matrix as does stimulation throughout the full 8 day sequence. The pattern of stimulation of chondrogenesis by PEMF appears to be similar to that produced by the administration of growth factors on day 2 of development.

These studies suggest that, in this model of experimental endochondral bone formation, there are differing sensitivities among developmental sequences to stimulation with PEMF with the system being most sensitive during the early phases of development.

G-1-3 **EXTREMELY LOW-AMPLITUDE, LOW-FREQUENCY ELECTRIC FIELD (EF) STIMULATED BONE CELL PROLIFERATION WAS ASSOCIATED WITH BOTH INCREASED MESSAGE AND PROTEIN FOR IFG-II IN THE HUMAN OSTEOSARCOMA CELL LINE, TE-85.** R. J. Fitzsimmons, S. Mohan, D. Strong, W.R. Adey, and D. J. Baylink. Depts. of Medicine and Biochemistry, Loma Linda Univ. and Pettis VA Hospital, Loma Linda, CA.

Because in vivo experiments have demonstrated increased bone formation in response to electrical stimulation, it is hypothesized that in bone mechanical energy is transduced into biologically relevant electrical energy. Therefore, we have developed an in vitro model in order to study the mechanism of EF effects on skeletal tissue. Utilizing our model (capacitively coupled, extremely low amplitude - 10^{-5}V/m) we have shown that EF-stimulation increased bone cell proliferation in both tibiae organ cultures and in monolayer chick calvarial cultures. In these experiments we tested whether the human osteosarcoma cell line, TE-85, would also respond to EF-stimulation. We found a frequency response for increased cell proliferation following a 30 min. exposure to the EF with a peak at or near 14 Hz. We also found that a 14 Hz EF-exposure (a) increased mitogen activity in the culture medium (+52 +/- 13%, $p<.001$), (b) increased mRNA for IGF-II (+210%), and (c) increased IGF-II (+88%) in the culture medium. Therefore, IGF-II may play an important role in mediating EF-stimulated bone cell proliferation. In summary, we have shown that exposure to an extremely low-amplitude EF can increase human derived bone cell proliferation in a frequency dependent manner and increase both the protein and message for IGF-II.

G-1-4 **LOW-ENERGY ELECTROMAGNETIC FIELDS (LEMF) MODULATE SIGNAL TRANSDUCTION BY G PROTEIN-LINKED MEMBRANE RECEPTORS: COMPARISON OF EFFECTS ON PARATHYROID HORMONE RECEPTORS AND BETA-ADRENERGIC RECEPTORS IN BONE CELLS.** R.A. Luben. Division of Biomedical Sciences and Department of Biochemistry, University of California, Riverside, CA 92521.

Electromagnetic fields of low energy (1-10 mV/cm) and low frequency (<100 Hz) have been shown to produce physiologic and behavioral effects on many systems. Bone and neural systems have been consistently demonstrated to respond to LEMF in living organisms and in vitro. We have shown that LEMFs which stimulate bone fracture repair in vivo can also act on isolated bone cells in vitro to increase their rates of differentiation and matrix synthesis. The primary effect appears to be modulation of signal transduction by the parathyroid hormone (PTH) receptor, a member of the G protein-linked gene family which also includes receptors for light, neurotransmitters and other hormones. In the current studies we compared effects of LEMF on PTH receptors and ß-adrenergic receptors in cultured osteoblasts. Exposure to pulse-train LEMF at 15 Hz (Bi-osteogen) reproducibly inhibited adenylate cyclase activation by PTH (max. inhibition 82%) and by the ß-adrenergic agonist isoproterenol (max. inhib. 38%), but not by forskolin, a receptor-independent activator of adenylate cyclase. Net levels of Gi and Gs proteins measured by ADP-ribosylation were not changed by LEMF, suggesting that the observed effects were specific either for receptor/ligand or receptor/G protein interactions. Binding of ^{125}I-PTH analog to PTH receptors was not affected by LEMF either in terms of Ka or Bmax, but there was a decrease in binding of monoclonal antibodies recognizing extracellular domains of the receptor, suggesting a change in receptor conformation in a region close to the putative G protein association site. In studies of the ß-adrenergic receptor, LEMF did produce a time dependent 50% decrease in apparent Ka but not in Bmax for the ß-adrenergic receptor ligand ^{125}I-cyanopindolol. Taken together, these data suggest that LEMFs may cause transient changes in the stereochemical configuration and signal transduction properties of at least two G protein-linked membrane receptor molecules. This raises the possibility that members of this class of receptors may serve as principal mediators of electromagnetic bioeffects in other tissues as well.

Supported by DOE Contract DE AI01-79ET29078 and NIH Grant AR 39241.

G-1-5 **TRANSCRIPTIONAL CHANGES IN HL60 CELLS EXPOSED TO ELF ELECTROMAGNETIC FIELDS.** Reba Goodman and Ann Shirley-Henderson. Department of Pathology, Columbia University Health Sciences, New York, NY 10032, Department of Biological Sciences, Hunter College-CUNY, New York, NY 10021.

The effects of exposure of cells to defined extremely low frequency (elf) electromagnetic fields (EMFs) will be reviewed with emphasis on transcriptional and translational changes. The exposure of the cells to non-ionizing radiation results in a pronounced measurable response observed as transcript increase, with associated changes in protein synthesis. The major finding relative to exposure of cells to elf EMFs are fourfold: (1) transcript changes in cells occurs directly at the chromosomal level; (2) frequency-, amplitude- and time-dependent "windows" are observed relative to quantitative changes in transcript levels; (3) genes not normally expressed in HL60 cells are unaffected by exposure to elf EMFs, and (4) specific changes in the overall protein synthetic pattern have been observed. [Supported by ONR, EPRI, DOE and EBI].

G-1-6 **SIMULATION OF LORENTZ FORCE EFFECTS ON ION BINDING KINETICS.** Jonathan J. Kaufman, Alessandro Chiabrera*, Mona Hatem, and Arthur A. Pilla. Bioelectrochemistry Lab, Dept. of Orthopaedics, Mount Sinai School of Medicine, New York, NY 10029 and *Department of Biophysical and Electronic Engineering, University of Genoa, Genoa, Italy.

Low level electromagnetic fields have been reported to affect many biological processes, although a fundamental understanding of the basis of these phenomena has yet to be presented. A recently proposed mechanism for low-frequency resonant type electromagnetic field bioeffects is based on the Lorentz force. Under noise free conditions, Lorentz force analysis does predict resonant phenomena related to the motion of charged ligands. Recently, however, theoretical analyses have thrown into question the physical relevance of the Lorentz force and direct ion interaction to electromagnetic bioeffects. In this work we use computer simulation studies to further elucidate the role of Lorentz force in modifying the rate at which a charged ligand dissociates from a binding site or receptor. We estimate the mean first exit time t_o, or the average time for the ligand to escape from a binding site, using a Monte Carlo numerical integration approach. We incorporate the effects of thermal noise, endogenous forces, as well as exogenous electric and magnetic fields. The mean first exit time is evaluated as a function of sinusoidal exogenous magnetic field frequency and amplitude, and the conditions discussed for which it may be modified. This approach also includes the effect of excess noise on ligand binding kinetics, and thus is more general than an equilibrium thermodynamics based analysis.

G-1-7 **KINETICS AT THE MEMBRANE SURFACE ARE TARGET PATHWAYS FOR WEAK ELECTROMAGNETIC FIELDS.** A.A. Pilla, J.M. Alves, P. Duarte-Alves, J.J. Kaufman, and J.T. Ryaby. Bioelectrochemistry Laboratory, Department of Orthopaedics, Mount Sinai school of Medicine, New York, NY 10029.

It was originally proposed (AAP) that weak electromagnetic fields (EMF) could modulate the rate of biological processes by affecting the rate of ion binding at the cell surface. This may trigger second messengers and an overall cellular response ensues. This proposal has been tested by measuring the electrical properties of MC3T3 clonal osteoblasts in the presence of clinical and research EMF signals. Osteoblast impedance is evaluated by measuring their electrical response while entrapped in the cylindrical pores of polycarbonate filter. A broad band (50 Hz - 10 MHz) estimate of the electrical membrane impedance is obtained in the presence and absence of externally applied EMF. The results show that the EMF affects the equivalent adsorption resistance (by nearly 10 times) indicating that ion binding kinetics are a target pathway. This suggests that matching the spectral content of the EMF to that of the observed electrical response would allow the stimulus to be most efficiently coupled to the ion binding target pathway. This was tested by examining the effect of EMF pulse width from 50 to 300 μsec at constant amplitude on Ca^{2+} uptake and adenylate cyclase activity in MC3T3 osteoblasts. The results show that a maximum effect of approximately 100% occurs at 100 μsec suggesting that signal energy at relatively high frequencies is important for dosimetry, appearing to support the hypothesis that electric field coupling of the applied signal is necessary for an EMF modulated bioeffect.

G-1-8 **PHYSICAL MECHANISMS FOR ELECTRO-MAGNETIC STIMULATION OF TISSUE GROWTH AND CELL DIFFERENTIATION.** Charles Polk. Dept. of Electric Engineering, University of Rhode Island, Kingston, RI 02881.

Any explanation for electro-magnetic stimulation of tissue growth or cell differentiation in terms of established physical laws must rely on the following experimental observations: (1) The magnitudes of the peak instantaneous electric currents, induced by typical magnetic signals that are used clinically for stimulation of bone growth, are about equal to the smallest known endogenous currents in humans. Currents induced by these signals in experimental animals (rats), in which effects on bone development has been established, are smaller than known endogenous currents. (2) Peak instantaneous electric fields indicated by these magnetic signals in cell and organ cultures, where effects on transcription have been noted, would produce transmembrane potentials that are many orders of magnitude below endogenous values. (3) Time average values of the induced fields and currents are always many orders of magnitude below endogenous field and current levels. (4)

Different wave shapes and repetition rates of non-sinusoidal signals, and different frequencies of sinusoidal signals have different physiological effects. (5) The magnitude of the electric fields induced by sinusoidally time varying magnetic fields would increase linearly with frequency within frequency bands where the electrical properties of the (homogeneous) tissue or cell culture remain constant. Observed physiological effects of such signals are generally not proportional to frequency.

Since the values of the induced electric fields in humans are marginally large enough to mimic endogenous fields, but are too small to produce significant currents or changes of electric charge distribution in small animals or in cell or organ cultures, one arrives at the conclusion that direct action of the applied magnetic field, as well as action of the induced electric field must be considered. Review of known magnetochemical effects that can occur at the field intensities commonly employed then indicates that only changes of chemical reaction rates, rather than formation of new compounds, is to be expected.

SESSION H-1: **THERAPEUTIC APPLICATIONS I**
Moderators: Whit Athey and Howard Wachtel

H-1-1 **WHOLE BODY PEMFS AS A MEANS OF PREVENTING DISUSE OSTEOPENIA IN MICE.** S. Simske, H. Wachtel, and M. Luttges. Bioserve Space Technologies, University of Colorado, Boulder CO 80309-0429.

Osteopenia (loss of bone) due to spaceflight has been simulated using hind-limb suspended rodents. PEMFs have been used previously to treat non-union fractures, indicating PEMF induced osteogenesis. Recently, we have shown that localized PEMFs are effective in reducing osteopenia induced by suspension (Simske, et al). In the present study whole body fields, produced by a Helmholtz arrangement of coils on the walls of the cages, were used to offset the degeneration normally induced by suspension. The magnetic fields produced by these coils could be directly monitored and no constraining or irritating cuffs were needed. 64 male mice (50 days old) were randomly assigned to control (20), suspended (12) or suspended and field-treated (32) groups. 8 of the control mice were sacrificed prior to the 2-week study period. The field-treated mice were exposed to one of four fields having peak magnetic field change rates of 0.44, 1.32, 2.64 or 3.30 T/sec. The effects of suspension and suspension+field are assessed through the measurement (Instron 1331) of the force-deflection properties reflecting stiffness, strength, ductility and toughness ($S, P_e, P_m, P_f, \delta_e, \delta_m, \delta_f, A_e, A_m$ and A_T) as well as whole bone weight and porosity estimations. The results indicate that some of these fields may

result in significant prevention of the degenerative changes normally manifested in suspended mice. Comparison to the controls indicates that suspension may act primarily, through growth suppression which the PEMFs may offset by increased osteogenesis.

H-1-2 **EFFICACY OF CRANIAL ELECTROSTIMULATION (CES) FOR RELIEF OF SYMPTOMS ASSOCIATED WITH AFFECTIVE DISORDER AND SUBSTANCE WITHDRAWAL.** Mary Ellen O'Connor, Faust Bianco* and Robert Nicholson*. Department of Psychology, the University of Tulsa, Tulsa, OK 74104.

A meta-analysis to determine the effectiveness of CES for the alleviation of symptoms associated with affective disorder and substance withdrawal from alcohol and other addictions was performed. A number of studies were screened for design and procedure adequacy (e.g., double-blind, inappropriate statistical techniques, adequate sample size) and only those that met the criteria were used in the analysis. The selection was performed independently by two raters who were not aware of the outcome or conclusions of any of the studies. The purpose of meta-analysis is to arrive at a statistical conclusion using information from a number of studies. This type of analysis is particularly indicated for areas where the literature contains studies reporting statistically significant positive results, trends and non-significant results following a specific treatment.

H-1-3 **EFFECTS OF 26-MHz ON SKIN WOUND HEALING IN THE GUINEA PIG.** R.H.C. Bentall and D. Beard*. Bioelectronics Corp., Technology Advancement Program, College Park, Md. 20742.

A wound healing model incorporating primary and secondary wounds was used to evaluate the effect of pulsed radio frequency energy on tensile strength as measured by skin wound healing in the guinea pig. In this blinded study, 64 animals each had a tear-shaped wound incised on their flank. This wound was designed to maximize the likelihood of dehiscence in the primary portion adjacent to the secondary wound. Each animal was randomly allocated an RF emitting device which was fixed around the thorax by a harness, treatment was thus continuous. The device characteristics were: pulse modulation 1040/s, carrier frequency 26 MHz, average available power output 477 $\mu W/cm^2$, pulse width 80 ms. Sutures were removed at either three or four days post-operatively and certain of these wounds dehisced. In the three day group of 19 placebo and 20 actively treated animals, there was a significant (18%) difference ($p<0.00004$) between the two groups' mean wound area measurement in the dehisced wounds' eschar size. It seems that this was mainly due to a 35% (active) to 16.7% (placebo) difference ($p<0.05$) in the number of wounds which did not dehisce, which accounts for the overall wound size differential. In the four day group of 11 placebo, and 9 actively treated animals, there was an overall 10% similar reduction ($p<0.03$) in the mean area differences. During the

rapid healing phase (days 12-21) there was a mean 50% reduction in the actively treated groups' area as compared to the placebo groups' area ($p<0.0007$) for the same period. These figures are in keeping with our previous rat tensile strength findings, and suggest that this may be due to collagen being laid down earlier in the actively treated wounds. These findings would suggest very significant benefits in post-operative surgery if this same trend is found in humans. Final scar size was also reduced in the active as compared to placebo groups.

H-1-4 **QUANTITATIVE EFFECTS OF WEAK ELECTROMAGNETIC FIELDS ON WOUND CLOSURE IN CULTURED CONFLUENT ENDOTHELIAL CELLS.** Ben Greenebaum, M. Oldani, F. Todd and E.M. Goodman. Biomedical Research Institute, University of Wisconsin-Parkside, Kenosha, WI 53141.

Endothelial cells derived from human umbilical veins were placed in culture within 3 hours of birth. The cells were maintained in T-30 Primaria flasks (Falcon Plastics) containing medium 199 supplemented with 20% serum, heparin and endothelial growth factor. To perform an experiment, endothelial cells were grown for one week in 30 mm Petri dishes (containing 2 mm grids) that had been precoated with fibronectin. The confluent monolayer was wounded using a sterile glass needle. Following wounding, new medium without endothelial growth factor was added. An area of the wound was selected and measured using an image analysis system (Jandel Scientific) interfaced to an inverted microscope through a video camera. In experiments reported here, the same area was assessed for both control and EMF-exposure conditions. This approach minimized localize differences in the wound and provided better data with lower error bounds. In performing an experiment the initial wound area was measured and the coordinates noted. After a 60 min recovery period, the change in wound area was determined; subsequent measurements were made at 30 min intervals during the next two hour period. After three hours in the non-exposed control environment, a 1.8 mT peak pulse burst waveform was turned on and the rate of closure was assessed at 30 min intervals for an additional 3 hr period. The data show that the control area decreased about 16% during the 3 hr post wounding period whereas the EMF-exposed area decreased about 30% over the succeeding 3 hour exposure period. (Sponsored by NIGMS)

H-1-5 **SLEEP INDUCING EFFECTS OF LOW ENERGY EMISSION THERAPY.** Martin Reite, Lisa Higgs, Niels Kuster*, Jean-Pierre Lebet**, and Boris Pasche**. Department of Psychiatry, University of Colorado Health Sciences Center, Denver, CO 80262. Swiss Federal Institute of Technology, Electromagnetics Group, CH-8092-Zurich, Switzerland*. Symtonic SA, Av. des Baumettes 9, CH-1020-Renens, Switzerland**.

Low energy emission therapy (LEET) consists of the intrabuccal emission of amplitude modulated 27.12 MHz EM fields with modulation frequencies, ranging

from 0 to 10 KHz resulting in a SAR considerably below the present ANSI standards. A double-blind cross-over study was performed on 52 healthy subjects. They were seated on a chair, eyes closed with the antenna of the emitting device in the mouth. The physiological effects of LEET were assessed by recording for 15 minutes the electroencephalogram (EEG), the blood pressure and the pulse following 20 minutes of either active or inactive LEET treatment. EEG analysis according to the Loomis classification showed 32.96 +/- 26.72 and, 28.75 +/- 27.04 sleep pages for the active and the inactive treatments, respectively. The number of stage B2 sleep pages was significantly higher ($p<0.01$) in the active (13.94 +/- 14.44) than in the inactive (8.48 +/- 12.12) treatment group. These data strongly suggest that LEET may act as a sleep inducer.

H-1-6 **LOW ENERGY EMISSION THERAPY DECREASES THE AMPLITUDE OF ALPHA ACTIVITY.** Lisa Higgs, Martin Reite, Claude Rossel* and Boris Pasche*. Department of Psychiatry, University of Colorado Health Sciences Center, Denver, CO 80262. Symtonic SA, AV. des Baumettes 9, CH-1020-Renens, Switzerland*.

The effect of Low Energy Emission Therapy (LEET) on cerebral electrogenesis was investigated in a double-blind cross-over study on 18 patients. The subjects were treated twice for 20 minutes with at least one week interval between each of the active or inactive treatments. Each patient was asked to remain awake during the whole protocol. A 28 channel computerized electroencephalographic recording was performed before, immediately after and 5 minutes after each treatment. Delta, theta, alpha, beta 1 and beta 2 band amplitude were compared during eyes open and eyes closed conditions for all recordings. Alpha (8.2-11.7 Hz) amplitude during the eyes closed conditions showed a significant change ($P = 0.025$, two-tailed t-test) from post treatment to 5 minutes post treatment in the active (-50.87 +/- 90.61 μV) as compared with the inactive treatment group (33.50 +/- 51.47 μV). No changes were observed in beta, delta or theta amplitude. The data suggest that the initial effect of LEET on cerebral electrogenesis is a decrease of the amplitude of alpha activity.

SESSION H-2 **THERAPEUTIC APPLICATIONS II**
Moderators: C. K. Chou and James Lin

H-2-1 **INCREASE OF STAGE 2 NREM SLEEP IN CHRONIC INSOMNIACS AFTER 4 WEEK TREATMENT WITH LOW ENERGY EMISSION THERAPY.** Roza Hajdukovic, Milton Erman, Randy Cohen, Merrill Mitler, Alexandre Barbault*, and Boris Pasche*. Division of Sleep Medicine, Scripps Clinic and Research Foundation, La Jolla, CA 92037. Symtonic SA, Av. des Baumettes 9, CH-1020-Renens, Switzerland*.

The effect of Low Energy Emission Therapy (LEET) on the electrocortical activity of chronic insomniacs was investigated in a controlled double-blind study. The study was performed on a total of 30 subjects suffering from severe insomnia. Patients received a 20 minute LEET treatment in the late afternoon three times a week for a 4 week period. EEG recordings were obtained before and after the first and the last treatments. The increase of epochs of stage 2 NREM sleep was significantly higher at the $p<0.05$ level (two-tailed t-test) in the active (4.27 +/- 6.27) than in the inactive (0.80 +/- 2.07) treatment group. These data suggest that chronic insomniacs experience an increase in stage 2 NREM sleep immediately after the last session of the 4 week treatment with LEET.

H-2-2 **EFFECTIVENESS OF LOW ENERGY EMISSION THERAPY IN THE TREATMENT OF INSOMNIA.** Milton Erman, Roza Hajdukovic, Randy Cohen, Boris Pasche*, Claude Rossel*, and Merrill Mitler. Division of Sleep Medicine, Scripps Clinic and Research Foundation, La Jolla, CA. Symtonic SA, Renens, Switzerland*.

The effect of intrabuccally emitted 27 MHz amplitude-modulated electromagnetic fields (Low Energy Emission Therapy: LEET) was investigated in a controlled double-blind study. The study was performed on a total of 28 subjects suffering from severe insomnia. Patients received a 20 minute treatment in the late afternoon three times a week or a 4 week period. Patients received polysomnography twice, once before the treatment period and once after. Means of the 28 patients' response to treatment are reported in the following table:

	Treatment (n=19)			Placebo (n=19)		
	Pre	Post	Change	Pre	Post	Change
Sleep Efficiency (%)	54.1	73.1	19.0	68.3	67.1	-1.2
Total Sleep Time (min)	265.9	349.4	83.5	339.9	326.0	-12.9

There was a significant difference in sleep efficiency ($p<0.05$) and in total sleep time ($p<0.05$) between groups. These data, along with changes in EEG activity, provide the first look at a new non-pharmacological treatment for insomnia.

H-2-3 **LOW ENERGY HIGH FREQUENCY (27.12 MH_3) THERAPY FOR PERSISTENT NECK PAIN. A DOUBLE BLIND PLACEBO CONTROLLED TRIAL.** Darragh Foley-Nolan, C. Barry, R.J. Coughlan, P. O'Connor, and D. Roden. Mater Misericordiae Hospital, Dublin 7, Ireland.

Persistent neck pain is a difficult therapeutic problem. The cause is usually cervical spondylosis or post traumatic. 20 patients with persistent (seven or eight weeks duration) neck pain were enrolled in a double blind placebo controlled therapeutic trial of low energy pulsed electromagnetic therapy PEMT units, which were enclosed in soft collars. After three weeks pain (visual analogue scale $P<0.023$) and range of movement (ROM) ($P<0.02$) had improved in the group on active treatment compared to controls. For the second three weeks of the study all patients used active units. There were significant improvements ($P<0.02$) in observed scores of pain and ROM. By the end of the study seventeen of the twenty patients enrolled felt "moderately" or "much" better. PEMT in the form described is easy to use in the home-setting, without side-effects and has previously been shown to be effective in soft tissue injuries. In conclusion PEMT has a definite role in the treatment of persistent neck pain.

SESSION C-2:	**POSTER SESSION 1**
Moderators:	Wendell Winters and Betty Sisken
SESSION C-3:	**POSTER SESSION 2**
Moderators:	Marvin Frazier and Richard Tell

IMMUNOLOGY

P-1 **STUDY OF THE EFFECTS OF STRONG ELF MAGNETIC FIELDS ON ANTIBODY RESPONSE AND NATURAL KILLER ACTIVITY IN MICE.** C. Bouthet*, A. Caristan, P. Deschaux, J.-M. Moreau, R. de Seze and B. Veyret. Laboratoire de Bioelectromagnetisme, EPHE, ENSCPB, Universite de Bordeaux I, 33405 Talence, France.

In a previous study, it was shown that slowly varying (0.8 Hz, square-wave) magnetic fields (up to 1200 Gauss) increased the NK cytotoxic activity in vivo depending on the age of the mice and on the intensity of the field. This work has been extended to the study of the effects of the magnetic fields on the antibody response. The mice (Balb/C, 6 to 24 wk old) were placed in the uniform field produced by 2 Helmotz coils for 5 days (10 hrs/day). Following exposure, the mice

were sacrificed and the spleens removed. NK activity was measured by the release of ^{51}Cr technique in which prelabeled YAC tumor target cells were lysed by splenic active effector cells. There is an increase of the NK activity with the intensity of the field (from 100 to 1200 Gauss) and with the age of the mice (starting with no effect at 6 wk). Experiments are being carried out to determine the role of the main physical parameters (modulation frequency, time derivative of the field, etc...). Evaluation of the antibody response was done by counting the number of plaque forming cells (PFC) at the end of exposure following immunization with sheep red blood cells at time zero. The PFC number for the exposed animals was significantly lower than that of the control at some low field intensity. Flow-cytofluorimetry was also used to observe the changes caused by the field in splenic lymphocyte sub-populations.

P-2 **STUDY OF THE EFFECTS OF PULSED AND AMPLITUDE-MODULATED LOW POWER MICROWAVES ON THE IMMUNE RESPONSE OF MICE.** R. de Seze*, A. Caristan, C. Bouthet*, P. Deschaux, M. Geffard*, J. Joussot-Dubien*, M. Le Diraison*, J.-M. Moreau and B. Veyret. Laboratoire de Bioelectromagnetisme, EPHE, ENSCPB, Universite de Bordeaux I, 33405 Talence, France.

In previous studies, it was found that exposure to low power (30 $\mu W/cm^2$) pulsed microwaves (9.4 GHz, 1 μsec pulse, 1000 pps), amplitude modulated at frequencies between 14 and 41 MHz (100% modulation) of immunized mice produced a marked immunomodulation which depended on the frequency of the modulation. In this new series of experiments, Balb/C mice (6 wk old males) were exposed 9 hrs/day with the same apparatus but with a larger average incident power (100 $\mu W/cm^2$). The harmonics content of the modulation signal was varied as well as the fundamental frequency between 0 and 100 MHz. In each of a first set of experiments, 20 mice were immunized with Bovine Serum Albumin (BSA) and 10 of them were then exposed for 4 days while 10 remained as control. Tests were then carried out using a cytofluorimeter in order to determine the effects of the microwaves on the peritoneal and splenic macrophage and lymphocyte sub-populations with no observable modification.

In each of a second set of experiments, 20 mice were immunized once with Sheep Red Blood Cells (SRBC), then 10 were exposed for 5 days and 10 remained as control. The spleen lymphocytes were counted on the 6th day and the number of plaque forming cells (PFC) was measured. The dependence of the number of PFC on the modulation frequency and harmonics content showed that a pure sinusoidal signal gave no effect while some combinations of harmonics produced significant immunomodulation. The correlation that exists between the two independent sets of results will be described.

P-3 **EFFECTS OF CONTINUOUS (CW) AND PULSED (PW) 2450MHz MICROWAVES ON PHYTOHEMAGGLUTININ (PHA)-INDUCED TRANSFORMATION OF HUMAN LYMPHOCYTES IN VITRO.**
E.M. Czerska*[1], E.C. Elson[2], C.C. Davis[3], and P. Czerski[1]. 1. Center for Devices and Radiological Health, FDA, Rockville, MD 20857, 2. Walter Reed Army Institute for Research, Washington, DC 20307, 3. Department of Electrical Engineering, University of Maryland, College Park, MD 20742.

Human peripheral blood lymphocytes in chromosome medium 1A (Gibco) with PHA at suboptimal concentration have been incubated for 72 hours, and exposed to conventional heating, or to CW or PW 2450 MHz at the same average SARS and temperatures using an exposure system with automated dosimetry, described in detail elsewhere (Joyner et al, Health Physics 56, 303-307, 1989). The cells were exposed over 72 h or over the 1st, 2nd, or 3rd 24 h of the incubation period. At harvest, cytocentrifuge (Cytospin II, Shandon) preparations were made, and stained with Wright-Giemsa. The numbers of untransformed, intermediate, and lymphoblastoid cells were determined based on their morphology, quantified using an Optomax image analyzer, and compared between experimental conditions and sham-exposed cells and cells incubated at 37°C. Following exposure to non-heating levels, CW exposure is without effects, while PW enhances transformation. Heating using conventional heat or CW (up to 2°C) enhances this process to a greater extent. Exposure to PW resulting in an increase of temperature by 1°C over the first 24 h is without effect, exposure over the second 24 h inhibits mitosis and decreases transformation, while exposure over the third 24 h results in enhancement to the same extent as exposure over 72 h.

DOSIMETRY

P-4 **USING A SPREADSHEET TO CALCULATE THE INDUCED CURRENT DISTRIBUTION PRODUCED BY LOW-FREQUENCY MAGNETIC FIELDS IN IRREGULARLY-SHAPED, INHOMOGENEOUS OBJECTS.**
Francis X. Hart. The Department of Physics, The University of the South, Sewanee, TN 37375.

This paper describes the use of an ordinary business spread sheet program to calculate numerically the current density distribution produced by a changing magnetic field. Each spread sheet cell corresponds to a current loop containing four impedances. An expression is obtained for the current in a given loop in terms of the currents in the four neighboring loops, the associated impedances, and the voltage induced around the given loop by the time-varying magnetic field. The resulting system of equations is solved by iteration. The method is validated by

comparison with the corresponding analytical solutions for concentric and excentric circular disks of differing resistivities. The method is then applied to a rectangle which is composed of a "U-shaped" region of resistivity r1 and a rectangle of resistivity r2 separating the arms of the "U". For r2>>r1 separate current loops are formed in the two arms and the current in the inclusion is negligible. As r2 decreases, more current flows through the inclusion and a single loop structure is formed throughout the rectangle. For r2<r1 the center of the loop is displaced further into the inclusion, which now dominates the circulation. This work is supported by the Electric Power Research Institute, contract RP2965-9.

P-5 **THE INDUCED FIELD DISTRIBUTION PRODUCED BY A NON-UNIFORM, ALTERNATING MAGNETIC FIELD.** Kenneth W. Wood* and Francis. X. Hart. The Department of Physics, The University of the South, Sewanee, TN 37375.

Although the experimental and theoretical analyses of magnetic field exposures are ordinarily carried out for uniform fields, circumstances exist when non-uniform field models would be more realistic. Traditional numerical methods for calculating the induced electric field distribution under these conditions are quite complicated. This paper describes how an ordinary business spreadsheet program can be used to compute the induced field distribution produced by a non-uniform magnetic field. This method is validated experimentally for a square, saline-filled dish placed at various positions within a pair of Helmholtz coils, only one of which is energized. The magnetic field within the dish is mapped using a Hall probe; the induced electric field, using a dual-dipole antenna. Good agreement is obtained between the measured and calculated values. This work is supported by the Electric Power Research Institute, contract RP2965-9.

P-6 **AC MAGNETIC FIELD MEASUREMENTS FROM STEREO HEADPHONES.** *Stephen Baumann and Sudar Alagarsamy.* Magnetoencephalography Laboratory, Division of Neurosurgery, University of Texas Medical Branch, Galveston, TX 77550.

Recent reports of bioeffects from low-intensity, ELF, magnetic fields led to an interest in determining the ac magnetic field strength produced by stereo headphones. A sampling of listening levels among headphone users revealed that 85-95 dB is the most typical range of sound levels preferred. A SQUID magnetometer (BTI model 607) housed in a shielded chamber was used to measure the magnetic field produced by various stereo headphones at 90 and 95 dB. Pure tones at one of three frequencies (220 Hz, 440 Hz, and 880 Hz) covering much of the range of popular music were played through the headphones. The magnetometer was positioned above one of the headphones along the axis of the coil within the speaker, and the magnetic flux density was measured at several distances of from 6-16 cm above the diaphragm. Because of amplifier saturation, it was necessary to infer the

field strength at closer distances based on the ratio of the radius of the coil to the measurement distance. At 90 dB the magnetic field from the different headphones was calculated to be 15-75 nT at a distance of 4 cm. This is the approximate distance of the coil in the headphones from the outer layers of the brain. At 95 dB the field strengths are sometimes 2-3 times larger and approach the level some investigators (e.g. Blackman et al., 1985) have found to cause biological effects. The use of stereo headphones by many people for long periods of time warrants a closer look at the magnetic fields produced by these devices.

P-7 **A MODEL FOR PREDICTING INDUCED BODY CURRENT IN WORKERS CLIMBING AM BROADCAST TOWERS.** Robert F. Cleveland, Jr. Federal Communications Commission, Washington, D.C. 20554; Edwin D. Mantiply. U.S. Environmental Protection Agency, Las Vegas, NV 89193-8517; and Richard A. Tell. Richard A. Tell Associates, Inc., Las Vegas, NV 89131.

We previously reported the results of a study in which induced body current was measured in an individual climbing a transmitting AM broadcast tower [Abstracts, 10th Annual Meeting, BEMS, 1988, p. 81; "Radiofrequency Electromagnetic Fields and Induced Currents in the Spokane, Washington Area" (EPA/520/6-88/008)]. Such studies are important since workers are known to climb these towers to perform maintenance tasks. In our earlier study we measured a peak induced body current of about 110 milliamperes on a one- kilowatt tower. This would correspond to an SAR in the wrist of about 18 W/kg. We also found that there was an excellent correlation between induced body current and the calculated radial component of the electric field (correlation coefficient = 0.98). In situations where it may be necessary for personnel to climb active towers it is essential to determine if power can be lowered to a level such that specific absorption rates (SAR) will not exceed recommended guidelines such as those of the American National Standards Institute or the National Council on Radiation Protection and Measurements. As a first step, we have calculated radial electric field for several typical AM towers with various: electrical heights and predicted what body currents (and peak SAR values) would be expected if the above relationship holds. From these models we have determined power levels or tower locations for which the recommended SAR limits would theoretically not be exceeded. Measurements on other AM towers can be compared with these theoretical values.

P-8 **NEAR-FIELD MEASUREMENTS OF AVERAGE SAR AND RF BODY-TO-GROUND CURRENT IN A FULL-SIZE HUMAN MODEL AT 10.2250, 16.6857, AND 29.9000 MHz.** Toby A. Griner and Richard G. Olsen. Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508-5700.

To study radiofrequency (RF) energy disposition caused by near-field irradiation from a typical shipboard antenna, we measured average specific absorption rates (SARs) and RF body-to-ground current in full-size muscle-equivalent human

models at three frequencies. We measured RF current-to-ground with the GC-2 RF current meter (University of Utah). By combining our present SAR results at 10.2250 MHz and previous SAR results at 16.6857 and 29.9000 MHz, we constructed an empirical relationship between body-to-ground current and whole-body SAR. This allows us to estimate whole-body SAR from measurements of RF body-to-ground current for certain near-field irradiation conditions. Results show that the whole-body SAR is a strong function of the squared RF current-to-ground measured in both legs. We believe that this relationship may provide a means to translate easily measured RF current-to-ground into whole-body SAR at the work site. It already has proven useful in evaluating methods of reducing SAR near shipboard high-frequency antennas.

P-9 **BODY CURRENTS FROM HF/VHF ANTENNAS AND RF HEAT SEALERS.** S.G. Allen, R.P. Blackwell*, P.J. Chadwick*, P.J. Dimbylow*1 and C. Unsworth*. National Radiological Protection Board, Cookridge, Leeds LS16 6RW, UK. NRPB Chilton, Didcot, Oxon OX11 ORQ.

A current transformer approach has been used to investigate induced currents in the limbs of people from a variety of HF and VHF sources including fixed station and vehicle mounted antennas, and RF dielectric welding machines. Electric field strength measurements have been used as input for computer models using finite-difference time-domain (FDTD) calculations. In many cases good agreement has been obtained between calculated and measured ankle currents and the results reviewed with respect to the NRPB guidelines which restrict extremity SAR to 20 W/kg and induced currents to 100 mA. Whilst there are some situations close to various antenna systems which indicate that exposure control may be necessary, by far the most significant occupational exposure problems arise with the RF welding machines. It is not uncommon for the basic restrictions on wrist and ankle exposure to be exceeded even when machine duty cycle corrections are made.

P-10 **SAR PATTERNS OF A MICROWAVE GYNECOLOGICAL APPLICATOR (FLETCHER-SUIT).** Mark J. Hagmann, Charles F. Gottlieb, Tadeusz M. Babij, Ronald L. Levin*, Pavel V. Houdek*, and James G. Schwade*. Florida International University, Miami, FL 33199 (MJH, TMB), University of Miami School of Medicine, Miami, FL 33136 (CFG, PVH, JGS) and BEIB/DRS, National Institutes of Health, Bethesda, MD 20892 (RLL).

A system for combined radiotherapy and microwave hyperthermia was built by RCA for the National Institutes of Health, following the design of the Fletcher-Suit gynecological intracavity applicator. Two microwave dipole antennas are mounted in the tandem, and one in each colpostat. The operating frequency is 2450 MHz. We have measured the heating patterns of this modified Fletcher-Suit applicator in a muscle-simulating phantom which is optically clear and has all ingredients in solution. Values of SAR were determined from measurements of the electric field

intensity using a miniature (3 mm diameter) implantable 3-dimensional electric field probe developed at the Center for Devices and Radiological Health, FDA. We have determined the SAR contours representing 80, 60, 40, and 20 percent of the maximum measured value. When the electric field probe is immediately adjacent to the components of the Fletcher-Suit apparatus at the locations of maximum SAR, the reading drops to 20 percent when the probe is moved a distance of approximately 4 mm from the tandem, or 7 mm from the colpostat.

P-11 **USE OF A MINIATURE ELECTRIC FIELD PROBE FOR DETERMINING THE SAR PATTERN OF AN EXTERNAL MICROWAVE HYPERTHERMIA APPLICATOR.** Tadeusz M. Babij, Mark J. Hagmann, Charles F. Gottlieb, Pavel V. Houdek*, and James G. Schwade*. Florida International University, Miami, FL 33199 (TMB, MJH) and University of Miami School of Medicine, Miami, FL 33136 (CFG, PVH, JGS).

We have measured the heating pattern of the BSD MA-151 external microwave applicator at a frequency of 915 MHz using a muscle-simulating phantom which is optically clear and has all ingredients in solution. The applicator was positioned with the bolus frame against the 5 mm thick sidewall of our cubical phantom (30 cm on a side); the water bolus was inflated to fill the void. Values of SAR were determined using a miniature isotropic electric field probe that was placed within the liquid phantom with a micropositioner. We have determined the SAR contours for 80, 60, 40 and 20 percent of the maximum measured SAR on four planes, spaced 5 mm apart, and oriented tangential to the sidewall of the phantom. Contours measured by the manufacturer at a depth of 1 cm are slightly larger than those which we have measured. This may be attributed to their use of a lower frequency (635 MHz), and to thermal smearing since a period of 2 min was used in their thermally determined SAR. Our contours have greater width in the E plane than the H plane, which is consistent with the greater dimension of the applicator in the H plane. This characteristic is not seen in the data from BSD. We conclude that rapid and accurate SAR determinations can be made using a miniature isotropic electric field probe in a liquid phantom.

P-12 **CURRENTS INDUCED IN AN ANATOMICALLY-BASED MODEL OF A HUMAN FOR EXPOSURE TO VERTICALLY POLARIZED EMP.** Om P. Gandhi and Jin-Yuan Chen. Department of Electrical Engineering, University of Utah, Salt Lake City, Utah 84112.

The finite-difference time-domain (FDTD) technique has been used to calculate the internal fields and the induced current densities as a function of time in anatomically based models of a human using 5,628 or 45,024 cubical cells of dimensions 2.62 and 1.31 cm, respectively. Because of the fairly narrow time steps needed for these cell dimensions, 0.04367 and 0.02183 ns, respectively, it was possible to represent the exact temporal variation of the incident fields of an electromagnetic pulse (EMP).

A layer of dielectric constants $\varepsilon_r = 4.2$ and thickness 2.62 cm was assumed under the feet to simulate a human wearing rubber-soled shoes. Total induced currents for the various horizontal sections of the body and the specific absorptions for the whole body and the various organs (brain, heart, lung, liver, kidney, and ankle) have been obtained for three representative EMPs with peak E-fields as high as 53 kV/m. Also obtained are the peak currents and the corresponding times for each of the cells in the body. The data will be presented for the contours of the peak current densities for the sections of the human body through the neck, the heart, the liver, the bladder, the knee and the ankle. Because of the time-domain representation, the FDTD method has been found to be ideally suited for exact representation of the pulse shapes and offers numerical efficiency to allow detailed modeling of the human body and its various organs.

P-13 **STEERING SAR PATTERNS OF ARRAYS OF SUBMILLIMETER INTERSTITIAL MICROWAVE APPLICATORS.** Charles F. Gottlieb, Tadeusz M. Babij, Mark J. Hagmann, Pavel V. Houdek*, and James G. Schwade*. University of Miami School of Medicine, Miami, FL 33136 (CFG, PVH, JGS) and Florida International University, Miami, FL 33199 (TMB, MJH).

We have previously described the fabrication of submillimeter applicators as small as 0.20 mm in diameter, and their testing, both singularly and in arrays, in phantoms and animals. We presently report our studies using an array of four 0.33 mm applicators located in Teflon Catheters on a two-cm square in a tissue-equivalent phantom. Microwave attenuators and phase shifters were used to adjust the magnitude and phase of microwave power supplied to each applicator to control the resultant heating pattern measured in the phantom. Our muscle-simulating phantom is optically clear, has all ingredients in solution, and is, therefore, homogeneous. Heating patterns were determined from measurements of the electric field intensity by using a miniature implantable three-dimensional electric field probe. Contours for 80, 60, 40, and 20 percent of the maximum SAR have been determined in a plane that is perpendicular to the applicators, and that passes through the gap in the outer conductor of each applicator. The location of the maximum SAR may be shifted by adjusting magnitude and phase, as has been previously shown for arrays of larger diameter interstitial applicators. We conclude that the heating pattern of an array of submillimeter applicators can thus be controlled. (Supported in part by ACS, Florida Division Martha H. McDonald Research Grant No. F88UM-2(Gottlieb))

P-14 **SAR APPROXIMATION IN THE NEAR FIELD OF SOURCES USING FREE SPACE H-FIELD VALUES.** Niels Kuster. Swiss Federal Institute of Technology (ETH), 8092 Zurich, Switzerland; Quirino Balzano. Motorola Inc., Plantation, Florida.

The goal of this study is to find a simple relation between free E- and H-fields in the vicinity of RF sources and the corresponding exposure SAR values. Experimental data show that the free E-field near sources is not simply correlated with the corresponding SAR distribution in phantoms, as the E-field undergoes, near sources, radical structural changes in presence of conductive bodies of arbitrary shape. It was found experimentally that the free space H-field tracks the SAR distribution in simulated tissue located in the proximity of antennas.

With the intent to find a simple relation between peak SAR value and external free H-fields, initially only the simple flat phantom is used to validate the relation experimentally and numerically (MMP3D Program Package). The results are then extended to curved surfaces. It was determined that the highest SAR value is always lower than $4x(H/d)^2/\sigma$, where H is the free space incident field, d is the phantom skin depth and σ is the conductivity of the phantom material. In the vicinity of antennas such as whips and helices the free space radiated H field can be computed using simple formulas for distances as small as $\lambda/100$.

For a more refined approximation, we will discuss the definition of a H-field reflection coefficient, which depends on the distance between the RF source and the phantom, frequency, the phantom electrical parameters and its geometry.

P-15 **MICROWAVE AND ACOUSTIC DOSIMETRY IN YOUNG ADULT CHINCHILLAS EXPOSED TO HIGH PEAK MICROWAVE POWER.** James C. Lin, Howard Bassen*, and Dennis Brown**. Department of Bioengineering, University of Illinois, Chicago, IL 60680; Walter Reed Army Institute of Research, Washington, DC 20307; **ERC Bioservices Corp, Rockville, MD 20850.

The objective of this research is to determine the effects of high peak power microwave-induced thermoelastic pressure waves on the sensory epithelium of the inner ear. Specifically, young adult chinchillas (1.0-2.5 yr. old) are exposed to high peak power, pulsed 1.25 GHz microwaves. The organ of Corti is examined microscopically following acute exposure to assess any damage to the cochlea. Six animals are used for a quantitative assessment of distribution of absorbed microwave energy and induced thermoelastic pressure waves in the head. The specific activities include: testing of waveguide exposure apparatus for chinchillas; exposure of chinchillas to pulsed microwaves; measurement of microwave exposure and absorption parameters, and thermoelastic pressures. A fiberoptic thermometry

probe and an infrared thermographic camera are used for determination of specific absorption rates (SAR) in the head and a broadband needle hydrophone is used to record transient acoustic pressure in cadaver and anesthetized chinchillas. For 500 KW peak powers of 20 microseconds in duration, the temporal peak SAR and maximum peak-to-peak acoustic amplitude in the midbrain are 1.5 MW/kg and 12 KN/m^2, respectively.

P-16 **IN-SITU MONITORING FOR BIOELECTROMAGNETIC EFFECTS FROM THE ELF COMMUNICATIONS SYSTEM.** John E. Zapotosky. Electromagnetics and Electronics Department, ITT Research Institute, Chicago, IL 60616.

A long-term, in-situ program is being conducted to monitor for possible effects from operation of the U.S. Navy's ELF Communications System to resident biota and their ecological relationships. The ELF System consists of two transmitters which synchronously broadcasts messages using FSK modulated signals centered primarily at 76 Hz. Transmitters became fully operational in 1985 and 1989 at Wisconsin and Michigan locations, respectively. Studies use a split-plot (in space and time) to examine for differences in biological and ecological variables. Treatment sites are located close to the overhead antenna wires and/or buried grounding elements of the transmitters, while control sites are located at a distance to insure that ELF System EM exposures are at least an order of magnitude less than those at the treatment sites. Physiological, development, behavioral, and ecological variables for upland, wetland and riverine organisms are being examined. Data collection for studies at the Wisconsin Transmitting Facility were concluded in 1989. Although some significant differences between sites were occasionally found for slime mold, bird, and wetland biota variables, there were no consistent within- or between-year patterns. In Michigan, a preoperational data base has been established, and it is anticipated that data collection will continue through 1991. To date, investigators conclude that the EM fields produced by an intermittently energized, or a fully operational, transmitting facility have had no measurable effects on exposed biota.

P-17 **BILAYERED DIELECTRICS MEASUREMENT WITH AN OPEN-ENDED COAXIAL LINE SENSOR.** Gang-wu Chen and Kang Li. Department of Electronic Engineering, Shandong University, Jinan, Shandong, China.

The measurement of reflection from an open-ended coaxial line is a simple and nondestructive technique to determine the dielectric properties of biological tissue or other materials. In this paper, an equivalent circuit of an open-ended coaxial line used as a sensor for bilayered dielectric measurement is obtained from a theoretical analysis. According to this equivalent circuit, the total complex capacitance of the sensor can be approximately expressed in the form $C_T=C_f + C_{\infty 1}{}^*+C_1(\varepsilon_2{}^*-\varepsilon_1{}^*)$, where the capacitance C_f represents the electric field concentration inside the

coaxial line, C_o is the sensor air fringing capacitance. C_1 can be determined by solving a rather complex integral equation. It depends on not only the geometric size of the coaxial line, but also the first layer thickness d. In our work, the capacitance of the line immersed in a water layer backed by air wall and a layer of transformer oil backed by air wall were measured experimentally and calculated theoretically by using the above equation, and it is shown that the theoretical results compared well with the experimental results. This paper also proposes a calibration method which makes use of four kinds of saline solution with well known dielectric properties. This procedure improves the accuracy of the measurement. (Supported by National Natural Science Foundation of China)

INSTRUMENTATION

P-18 **OBJECTIVE ASSESSMENT OF INFRARED CLINICAL IMAGES.** James C. Montoro, Ildiko M. Gyimesi and Michael Anbar. Department of Biophysical Sciences, School of Medicine, SUNY, Buffalo, NY 14214.

The distribution of temperature over different regions of the human skin is being used to diagnose a variety of neurological and vascular anomalies. To obtain reliable information on the temperature distribution one uses the scanning digital infrared camera, which can display an image of the IR black body flux, essentially producing a temperature map of the object examined. Similarly to classical radiology, conventional thermography uses human experimental expertise to assess pathology from abnormal patterns of these images, or from temporal changes in the image when the subject undergoes certain short term or long term treatment. Since these temperature images are digital, they lend themselves to computational manipulations that extract objective diagnostic information that can be automatically compared with normative clinical data in a procedure that is free of human bias. Computational procedure can involve either pattern recognition of a static image, or a temporal analysis of many images taken sequentially over time. We have demonstrated each of these principles and applied them to different clinical problems:

A. Determination of the effect of prolonged wear of contact lenses on the human cornea. We developed algorithms to analyze static thermal images, using the concentric nature of the eyeball, to qualitatively assess the occurrence of permanent "cold spot" on the cornea. From these data we calculated the statistical significance of our findings.

B. Assessment of neurological anomalies on the human back by a temporal analysis of many sequential thermal images that determines (using FFT) the frequencies of the underlying thermoregulatory oscillations. Pathology has been found to be associated with a non-uniform distribution of these regulatory frequencies and with the appearance if additional higher frequencies, which are absent in normal

subjects. In both these studies the assessment of pathology was objective, without calling for human expertise to diagnose a disorder by visual examination of the clinical image.

P-19 **CENTER FOR BASIC RESEARCH IN RADIATION BIOEFFECTS.** Martin L. Meltz. Department Radiology, The University of Texas Health Science Center, San Antonio, TX 78284.

A unique radiation facility allowing for simultaneous x-ray (or UV) and microwave (MW) radiation exposures has been constructed in the Dept. of Radiology at the University of Texas Health Science Center at San Antonio. The anechoic chamber is lined with stainless foil and RF absorbing material, and is built within a lead lined room. The anechoic chamber is both temperature and humidity controlled, allowing for animal exposures at different combinations of temperature and humidity, and in vitro exposures at warm room (37°C) temperatures. The chamber and the adjoining control room are shielded electronically from each other, and from the outside area. The x-rays are supplied by a Maxitron Orthovoltage x-ray unit. Brackets are available in the ceiling to hold ultraviolet lamps and MW antenna horns for vertical downward exposures. A stand at one end of the chamber can be used for either supporting circular waveguides, or for horizontal exposures from an antenna horn. A custom made transmitter allows for continuous wave or pulsed wave exposures, with or without amplitude modulation, at 915 MHz and 2.45 GHz. Animal exposures can be observed using a low light level color camera installed in the chamber, and temperature continuously monitored using a BSD-200 Thermometry System. This facility has been funded co-jointly by URIP Grant No. AFOSR-87-0029, and the University of Texas Permanent University Fund.

P-20 **THERMAL IMAGING BY MULTIFREQUENCY MICROWAVE RADIOMETRY.** Fernando Bardati, Valerie Brown, Giorgio Lovisolo, Michael Ross, and Piero Tognolatti. Dipartimento di Ingegneria Elettronica, Universita di Roma "Tor Vergata", Rome 00173, Italy.

To ascertain the capability of multifrequency microwave radiometry for imaging an inhomogeneous temperature distribution inside a cylindrical region of the human body such as a neck, a limb or a thigh, the theoretical problem of retrieving the temperature inside a phantom composed of a cylinder at temperature T+T embedded off-axis in a larger circular cylinder at uniform temperature T has been considered. Both cylinders are assumed to be filled by the same lossy dielectric material having the permittivity of muscle. Synthetic radiometric data have been generated at several frequencies in the 0.5-5.5 GHz band by rotating a 2 cm contacting antenna around the phantom on a plane normal to the axis. A singular system analysis of the integral operator relating the data to the phantom temperatures has been carried out. Temperature reconstructions have been performed for different values of measurement noise. In the numerical simulations the angular

position of the hotter area has been accurately retrieved, while the radial position has been found with less accuracy, the hotter area being generally shifted towards the border. An experimental activity has been started to validate the theoretical results. An already existing four-channel radiometer operating between 1.1 and 5.5 GHz is being used.

P-21 **AN AC AND DC MAGNETIC FIELD EXPOSURE SYSTEM FOR CELL AND ORGAN CULTURES.** D.L. Miller and L.E. Anderson. Pacific Northwest Laboratories, Richland, WA 99352.

Bioelectromagnetics experiments with in vitro cell and organ cultures require both a competent incubation system, and a versatile field generation system. A commercial incubator was fitted with a fan and duct work to transmit incubator conditioned-air to a separate exposure chamber. The incubator provides temperature, humidity, CO_2 atmosphere regulation. The exposure chamber was constructed, as much as possible, from plastic and other nonmetallic materials, and was mounted on a vibration isolation stand. The exposure chamber was enclosed by two sets of coils: A set of two 1.4 m square coils of 84 turns each, spaced 0.7 m apart, was arranged for vertical-field generation. A set of four 1 m by 1.2 m coils, two with 42 turns spaced 0.4 m apart and two with 60 turns spaced 1.2 m apart was arranged for horizontal-field generation. Another two complete sets of coils was also set up beside the exposure chamber and electrically paired with the first set to reduce the leakage fields of the system. The coils are energized by a function generator and power amplifiers to allow for modification of the local geomagnetic (DC) field and for AC magnetic-field generation in the ELF frequency range.

This project was supported by the Electric Power Research Institute.

P-22 **USE OF A 0.25 MM DIAMETER FLUOROPTIC TEMPERATURE PROBE FOR DETERMINING SAR.** Charles F. Gottlieb, Mark J. Hagmann, Tadeusz M. Babij, Pavel V. Houdek*and, and James G. Schwade*. University of Miami School of Medicine, Miami, FL 33136 (CFG, PVH, JGS) and Florida International University, Miami, FL 33199 (MJH, TMB).

We have previously presented SAR patterns for the BSD MA-251 applicator using 1) a miniature isotropic electric field probe, 2) a high resistance thermistor (Bowman), and 3) conventional (0.9 mm diameter) fluoroptic thermometry. The present study extends this earlier work by using a custom 0.25 mm diameter fluoroptic thermometry probe recently available from Luxtron. The applicator and temperature probes were located in Teflon catheters (size appropriate to each device) in a muscle-simulating phantom. This phantom is optically clear, has all ingredients in solution, and is, therefore, homogeneous; agar was used as a thickener to decrease convective heat transfer. We conclude that the new temperature sensors have accuracy comparable with the standard (0.9 mm diameter) fluoroptic probes. (Supported in part by ACS, Florida Division Martha H. McDonald Research Grant No. F88UM-2(Gottlieb))

P-23 **SOLENOIDAL MAGNETIC FIELD GENERATOR FOR BIOLOGICAL STUDIES WITH ELF FIELDS.** T.S Tenforde[1] and S.B. Merrick.[2] [1]Life Sciences Center, Battelle, Pacific Northwest Laboratory, Richland, WA 99352 and [2]Engineering Systems & Technology, Westinghouse Ford Corporation, Richland, WA 99352.

A solenoid driven by a high-power amplifier and series resonance circuit has been designed for exposure of cell suspensions to ELF fields at 60 Hz and harmonic frequencies. The power supply consists of a constant-current amplifier, a function generator supplying the desired waveform and signal frequency, and a resonant lock control circuit for precise frequency tuning. The inductive reactance of the coil is compensated by a discrete tuning capacitor at the frequency of interest to minimize the voltage across the power amplifier terminals. At 60 Hz the solenoid provides a uniform sinusoidal field with a peak flux density of 0.075 Tesla over a cylindrical volume of 0.1 liter (dB/dt = 20 Tesla/sec r.m.s.), and is capable of continuous operation for several days. The r.m.s. power dissipation in the oil-cooled copper coil is 450 W under these operating conditions. The complete exposure system contains monitoring instrumentation, including an ammeter, voltmeter, temperature sensor and gaussmeter, and protection equipment for the high-voltage components such as the tuning capacitor and the coil.

Research support received from the U.S. Department of Energy under Contract DE-ACO6-76RLO 1830 with the Pacific Northwest Laboratory. The Pacific Northwest Laboratory is operated for the U.S.D.O.E. by the Battelle Memorial Institute.

P-24 **ELF MAGNETIC FIELD EXPOSURE SYSTEM FOR LIFE STUDIES OF SMALL ANIMALS.** William E. Feero, Robert C. Patterson, and George A. Steiner. Electric Research & Management, Inc., State College, PA 16804.

A magnetic field exposure system which generates a uniform 60 Hz magnetic field in a rectangular volume has been developed for conducting lifetime studies of small animals. The coils provide sufficient space and clearances for encompassing the EPRI electric field exposure system operating at exposure levels of 100 kV/m. The outside dimension of the vertical field coils which lay in the horizontal plane are 4.15 meters by 1.55 meters and the horizontal field coils are 3.95 meters by 1.22 meters (the horizontal field coils are positioned in sets with one above the other in the vertical plane). Using the EPRI caging system for electric field studies, the number of animals per field exposure group is limited to 576, if mice are used for the lifetime study. Magnetic flux densities from 0 to 1 mT (0 to 10 gauss) can be generated independently in both the vertical and horizontal coils with a field uniform of 10% of mid-range. Independent control of the phase of the vertical and horizontal coils allows for linear, elliptical or circular polarization. Both the vertical

and horizontal coils contain a second winding which can be used to buck or boost the ambient dc earths' magnetic fields.

PHYSIOLOGY

P-25 **EFFECTS OF 60 Hz FIELDS ON HUMAN CARDIAC ACTIVITY: REVIEW AND INTEGRATION.** Mary R. Cook*, Charles Graham, Harvey D. Cohen, and Mary M. Gerkovich*.Midwest Research Institute, Kansas City, MO 64110.

In six double-blind studies we have repeatedly observed slowing of heart rate when young men were exposed to 60 Hz combined electric and magnetic fields. Both independent group and repeated measures designs have been used. The independent variables examined included exercise, field intensities (6 kV/m, 100 mG; 9 kV/m, 200 mG; 12 kV/m, 300 mG), and the rate at which the fields were turned on and off during the exposure periods. The heart rate slowing effect does not depend on the duration of exposure. It is larger when subjects are exposed to intermittent fields than when they are exposed to continuous fields. The effect was found at 9 kV/m, 200 mG but not at other intensities examined, suggesting that there may be a field intensity "window" effect. Consistent but puzzling order effect were observed in studies where each subject was used as his own control. These results and their implications will be discussed. (Research supported by the New York State Powerlines Project, the Environmental Protection Agency and the Department of Energy; presentation supported by DOE Grant DE-FG01-89-CE-34025.)

P-26 **PHYSIOLOGICAL EFFECTS OF WHOLE-BODY EXPOSURE TO MILLIMETER WAVES.** Melvin R. Frei, James R. Jauchem* and Melody Welch*. Trinity Univ., San Antonio, TX 78212 and USAF School of Aerosp. Med., Brooks AFB, TX 78235-5301.

In one of the first studies of whole-animal exposure to millimeter waves, ketamine-anesthetized Sprague-Dawley rats were irradiated in E and H orientations (long axis parallel to electric and magnetic fields, respectively) with 35-GHz continuous-wave radiofrequency radiation. Irradiation (whole-body average SARs of 13 W/kg in both orientations) was conducted to increase colonic temperature (T_c) by 1°C (from 38.5 to 39.5°C). During experimentation, colonic, tympanic, right and left subcutaneous temperatures, arterial blood pressure, and respiratory rate were continuously recorded. Under both exposure conditions, when irradiation commenced, there was a 3-5 min. delay in initiation of T_c change, and a 0.5°C T_c "overshoot" when irradiation was stopped. These events were caused by the extremely superficial energy deposition at this high frequency; conduction and circulatory transfer were responsible for internal heating. There were no significant

differences between orientations in the times required to achieve a 1°C T_e increase, or to recover to the initial T_e when irradiation was stopped. Subcutaneous temperature (side facing antenna) increases of 6.0°C accompanied the T_e increases in total orientations. Under both exposure conditions, heart rate and mean arterial blood pressure significantly increased during irradiation; however, there were no differences between E and H orientation responses. In summary, results show no difference between E- and H-orientation exposure at 35 GHz on sites of energy deposition and the attendant cardiovascular responses to irradiation. These findings are in contrast to the marked orientation differences previously noted during 700, 1200, and 2450-MHz irradiation of rats.

P-27 **FIELD ORIENTATION EFFECTS DURING 5.6-GHz RADIO-FREQUENCY IRRADIATION OF RATS.** Melvin R. Frei, James R. Jauchem*, Jimmy M. Padilla* and Danny L. Price*. Trinity Univ., San Antonio, TX 78212 and USAF School of Aerosp. Med., Brooks AFB, TX 78235-5301.

Ketamine-anesthetized Sprague-Dawley rats were exposed in E and H orientations (long axis parallel to electric and magnetic fields, respectively) to far-field 5.6-GHz continuous-wave radiofrequency radiation (RFR). Power densities were used that resulted in equivalent whole-body average specific absorption rates of 14 W/kg in both orientations (90 mW/cm^2 for E and 66 mW/cm^2 for H). Irradiation was conducted to increase colonic temperature by 1°C (from 38.5 to 39.5°C). During experimentation, arterial blood pressure and respiratory rate, colonic, tympanic, left and right subcutaneous (sides toward and away from RFR source), and tail temperatures, were continuously recorded. Results showed no significant differences between orientations in the times required to cause a 1°C increase or to recover to the initial temperature when irradiation was stopped. Significant differences between E- and H-orientation exposure were seen in the patterns of localized heating. The tail and left subcutaneous temperature increases were significantly greater during E-orientation exposure, the tympanic site showed no difference, and the right subcutaneous temperature increase was significantly greater during H-orientation exposure. Under both exposure conditions, heart rate and mean arterial blood pressure significantly increased during irradiation; however, there were no significant differences between E and H orientation responses. These findings at 5.6 GHz are in contrast to the marked cardiovascular response differences between E- and H-orientation exposure noted during a previous study of irradiation at 2.45 GHz.

P-28 **METABOLIC RATE IN UNANESTHETIZED AND KETAMINE-ANESTHETIZED RATS EXPOSED TO 2450-MHz RADIOFREQUENCY RADIATION.** James R. Jauchem* and Melvin R. Frei. USAF- School of Aerosp. Med., Brooks AFB, TX 78235-5301 and Trinity Univ. San Antonio, TX 78284.

In a previous study (Radiat Environ Biophys 28:155-164, 1989), differences in heating rates were noted between unanesthetized (but restrained) and ketamine-anestletized rats exposed to radiofrequency radiation (RFR). It was hypothesized that the faster rate of body temperature rise seen in unanesthetized rats was related, in part, to a difference in metabolic heat production. To test this hypothesis, oxygen consumption was measured in 11 Sprague-Dawley rats that were exposed to 2450-MHz RFR (power density, 60 mW/sq cm) in E orientation, first while anesthetized and restrained, and then while anesthetized with ketamine. Average whole-body specific absorption rate was approximately 14 W/kg. The time required for an increase in colonic temperature from 38.5 to 39.5 deg C when rats were anesthetized and restrained (mean +/- SEM, 4.2 +/- .4 min) was significantly less ($p < .05$, Student's t-test) than when they were anesthetized (5.6 +/- .4 min). Oxygen consumption in rats increased significantly (by 20 +/- 5 %) when in the unanesthetized, restrained state, but there was no significant change when anesthetized (an increase of 3 +/- 1%). The difference in metabolic heat production between anesthetized and unanesthetized animals during irradiation must be considered when studying RFR-induced thermal responses.

P-29 **A MAGNETITE-BASED MAGNETORECEPTOR IN COHO SALMON.** Michael H. Nesson[1] and Joseph L. Kirschvink.[2] [1]Department of Biochemistry and Biophysics, Oregon State University, Corvallis, OR 97331, and [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125.

The goal of this study is to locate and describe the magnetite-based sensory system presumably used by coho salmon (Oncorhynchus kisutch) to detect the geomagnetic field. Previous direct measurements by SQUID magnetometry had identified the dermethmoid bone in the snout region of the salmon skull as a site containing numerous single-domain crystals of the ferromagnetic mineral magnetite (Fe_3O_4). Electron microscope examination of magnetic extracts of digests of the dermethmoid tissue reveal 50nm diameter magnetite crystals which often appear to be arranged in chains. Light microscope histological studies allow identification of fibroblasts, abundant fat cells, capillaries, and nerve bundles comprising the soft tissue within the sinuses in the dermethmoid bone. An additional type of multicellular structure, resembling ducted glandular tissue, is frequently observed close to the adipose cells. Electron microscope examination of these structures has led to the tentative identification of magnetite crystals closely associated both with ciliary

structures (commonly a component of primary sensory cells), and with presumed axonal nerve processes. Electron microscope studies, including X-ray elemental mapping and electron microdiffraction, are currently underway to characterize unequivocally the biomineral particles and to provide a detailed understanding of the ultrastructure and the anatomy of a candidate for the primary transduction apparatus of a magnetoreceptive sensory modality. EPRI-RP2965-O8.

ENDOCRINE SYSTEM

P-30 **A 50Hz MAGNETIC FIELD EFFECTS AND PINEAL FUNCTION IN RAT: AN EXPOSURE SYSTEM.** Tsukasa Shigemitsu*, Izumi Nishimura*, Ken-ichi Honma and Masamichi Kato. CRIEPI*, Abiko, Chiba and Hokkaido University, Sapporo, Japan.

The purpose of this study is to investigate if exposure of rat to linear and/or circular polarized magnetic fields result in alterations of pineal hormone melatonin level. For this purpose, there is a need to develop a system for magnetic field exposure. Our initial efforts have focused on designing, fabricating and testing two identical magnetic field exposure systems. The exposure systems were built to give maximum flux density of 3G. Our approach was to use the square coil arrangements because of limitation in space. The system consists of two identical units mounted on about 1.8m square wooden supports. Each unit consists of 5 pairs of identically constructed square coils connected in series. Two units place with orthogonal axis. This system was to provide linear and/or circular polarized magnetic fields by adjusting the phase relationship of current between two units. A current of about 4A is needed to get a flux density of 3G. Magnetic field spatial uniformity has a coefficient of variation of about 1.4% less over exposure space. Minimum of 54 animals can be exposed. The total harmonic distortion of magnetic field was very low. The characteristics of exposure system will be discussed.

NERVOUS SYSTEM

P-31 **BEHAVIOR IN RHESUS MONKEYS EXPOSED TO HIGH PEAK POWER 5.6 GHz MICROWAVE PULSES.** John A. D'Andrea, John 0. de Lorge, and Al Thomas*. Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508-5700.

Four male rhesus monkeys (Macaca mulatta) were trained on an operant task for food pellet reward in an investigation of behavioral performance effects of very high peak power 5.6 GHz microwaves. The behavioral task required monkeys to press

one plastic lever reinforced on a variable interval schedule (VI-20 s) with a visual stimulus and then respond on a second lever to obtain food. The monkeys were conditioned to perform a color discrimination task using one of three colors displayed by fiber-optic cable. A red signal was associated with responding. If there was a response on the second lever when a green signal light was on, a food pellet was delivered; if a response was made in the presence of a white signal, there was a 10-s timeout. While performing the behavioral task, the monkeys were exposed to microwave pulses produced by a military radar (FPS-26A) and a pulse compression device (ITT-2972). Normal radar pulses were compared to radar pulses amplified by the pulse compression device and sham exposure. Peak field power densities were approximately 14 kW/cm2 and 3.9 kW/cm2 for the compressed microwave pulses and radar, respectively. The estimated peak whole-body SARs were approximately 880 kW/kg and 245 kW/kg. The microwave pulses (100 pps) were delivered for twenty minutes at a whole-body SAR of between 32.5 and 37.2 W/kg. Statistically significant alterations of behavioral performance were observed between microwave and sham exposures. There were no differences between the two microwave exposure conditions.

P-32 **EFFECTS OF EXPOSURE TO TEMPO PULSED HIGH-PEAK POWER MICROWAVE RADIATION.** B.J. Klauenberg, B.L. Cobb* and J.H. Merritt*. USAF School of Aerosp. Med., Brooks AFB, TX 78235-5301.

This report describes the third in a series of tests conducted to evaluate possible behavioral effects of TEMPO generated HPM in rats. The effects of HPM on startle response and performance on a rotarod device was reexamined in three strains of rats. In the startle test, two trains of 4 pulses (3.0 GHz, 20-40 ns, 0.5 pps, 45.9 (+/- 9.5 s.d.) kW/cm^2, $\leq$ 100 mJ, peak SAR = 1.0-6.9 MW/kg) separated by 1 min were delivered to rats in a startle box in a noise attenuating chamber. Neither pulse train produced a significant change in overall group activity. Startle amplitudes associated with the 1st pulse of each train (pulses 1,5) were larger in HPM rats than SH. There were no significant differences in proportion of animals exhibiting startle responses (HPM = 7/33 vs SH = 4/33) on the 1st pulse of the 1st pulse train. The proportion exhibiting startle responses to HPM (9/33) was higher than SH (1/33) during the 1st pulse of the 2nd train. One rat displayed dramatic startle responses, with no startle response to SH exposure, but large startle responses to each HPM pulse during all sessions. The dramatic response suggests that HPM was aversive to this particular rat. The underlying mechanism for this hypersensitive response is not known. Rats trained to walk on a slowly rotating rod were exposed to a train of 10 HPM or SH pulses (3.OGHz, 0.5 pps, 20-40 ns, 42.6 (+/- 13.2 s.d.) kW/cm^2, estimated local midbrain SAR=3.6 MW/kg). No effects of HPM on rotarod performance were observed. We suggest, based on all studies to date, that the HPM parameters are close to a threshold for behavioral effects.

P-33 **INFLUENCE OF MICROWAVE EXPOSURE ON CHLORDIAZEPOXIDE EFFECTS IN THE MOUSE STAIRCASE TEST.** Raymond M. Quock*, R. Richard Bixby, B. Jon Klauenberg and James H. Merritt. Radiation Sciences Division, USAF School of Aerospace Medicine, Brooks AFB, TX 78235.

To ascertain whether behavioral effects of benzodiazepines are altered by exposure to microwave radiation, we compared the performance of male, CDl mice in the staircase test 30 min after ip pretreatment with 8, 16 or 32 mg/kg chlordiazepoxide and immediately following a 5-min exposure to 4, 12 or 36 W/kg specific absorption rate (SAR) of microwave radiation (continuous wave) at a frequency of 1.8 or 4.7 GHz. In this paradigm, the number of steps ascended (NSA) and the number of rears (NR) exhibited by each mouse were recorded during a 3-min test period. Drug-induced reductions in NSA and NR are thought to reflect sedative and anxiolytic effects, respectively. In sham-exposed mice, chlordiazepoxide increased NSA without affecting NR at 8 mg/kg, increased NSA and decreased NR at 16 mg/kg, and decreased both NSA and NR at 32 mg/kg. Exposure to microwave radiation generally did not alter NSA or NR in mice pretreated with vehicle or 8 or 16 mg/kg chlordiazepoxide. However, in mice pretreated with 32 mg/kg chlordiazepoxide, exposure to 36 W/kg microwave radiation caused significant reversal of the reductions in NSA and NR. A significant effect of frequency was found at high SARs. One interpretation of these findings is that exposure to microwave radiation might reduce the sedative effect of chlordiazepoxide without affecting its anxiolytic effect.

P-34 **MEASURES OF SENSORY DETECTION BY RATS OF A 16 Hz SINUSOIDAL MAGNETIC FIELD BY THE TECHNIQUE OF CONDITIONAL SUPPRESSION.** Robert F. Smith, Rex L. Clarke, and Don R. Justesen. Behavioral Radiology Laboratory (151), USVA Medical Center Kansas City, Missouri 64128.

Earlier work in our laboratory revealed evidence of autonomic and behavioral sensitivity of mice, rats and a domestic bird to time-varying or d.c. magnetic fields circa 200-1,700 μT. To extend our previous work, we have designed and assembled and automated exposure and data-acquisition system. The system permits behavioral physiological data to be collected while small animals are exposed to a nearly uniform d.c. or time-varying magnetic field. In pilot studies to provide quality assurance - that the system and its fields are free of sensory artifact - each of three albino rats was first trained to suppress a lever-press response during a periodic, 3-min. presentations of a 2900-Hz sonic stimulus. After selective suppression was demonstrated, a 16-Hz field at 500-600 μT was paired with the sonic stimulus, which thereafter was gradually diminished until eliminated. In isolation, the magnetic field failed to suppress responding at the lever. In the absence of assays at differing field densities and frequencies, this finding has little generality for the

question of sensory detection, but it provides a strong warrant against the likelihood of spurious sensory stimulation. Formal studies with Long-Evans rats are now underway in which magnetic fields at each of several frequencies (e.g., 7, 16, 30, and 60 Hz) and under each of two conditions (sinusoidal and rectangular waves) are being assayed, not only for detectability but also for influence on motor activity and selected autonomic end points.

CELL BIOLOGY

P-35 **FURTHER STUDIES ON INTENSITY DEPENDENCE OF THE INDUCTION OF ACETYLCHOLINE ESTERASE ACTIVITY BY MODULATED RADIOFREQUENCY RADIATION.** S.K. Dutta, Kaberi Das*, and C.F. Blackman[1]. Department of Botany and Cancer Research Center; Howard University, Washington, DC 20059. [1]Health Effects Research Lab., US-EPA, Research Triangle Park, NC, 27711.

We have previously published data demonstrating that radiofrequency radiation (RFR) of 147 MHz, when amplitude modulated (AM) at 16 Hz, could cause alterations in the release of radiolabeled calcium ions from neuroblastoma cells in culture (NG-108-15; a mouse-hamster hybrid) at an SAR of 0.05 W/kg. We have also reported the results of a pilot study which showed that similar AM-RFR causes a change in the activity of acetylcholine esterase (AChE) in these cells at an SAR of 0.05 W/kg, but not at 0.005, 0.01 nor 0.10 W/kg. These responses indicated that there might be an SAR "window" similar to the ones observed for calcium release. In order to test this result further, cells were seeded and exposed for 30 minutes, and then assayed for acetylcholine esterase activity using ^{14}C-acetylcholine. We now report that an SAR of 0.02 W/kg causes a statistically significant ($p \leq 0.05$) enhancement in AChE activity in these cells; however, this only occurs when exposure is initiated within a narrow time "window" approximately 7.5 hours after seeding. These results confirm that AM-RFR can perturb nervous-system-derived cells in culture to affect both calcium-ion release and AChE activity in a common dose-dependent manner. (Supported partly by NIH RR-08016 and EPA CR812100 and R-813126)

This is an abstract of a proposed presentation and does not necessarily reflect EPA policy.

P-36 **ENHANCEMENT OF ORNITHINE DECARBOXYLASE ACTIVITY IN L929 CELLS BY AMPLITUDE MODULATED MICROWAVES.** David Krause, Julie A. Brent*, J. Michael Mullins*, L. Miguel Penafiel, and Roland M. Nardone*. Departments of Biology and Electrical Engineering, The Catholic University of America, Washington, DC 20064.

Some recent studies have indicated that electromagnetic radiation in the extremely low frequency and microwave range can cause modifications in the expression of cellular mRNAs and their translation product. One such protein is ornithine decarboxylase (ODC), the rate limiting enzyme in polyamine biosynthesis. This protein is inducible in tissue culture cells by many methods. Serum stimulation and the phorbol ester tumor promoters are among those agents which achieve the highest induction of ODC activity. In this study we were able to induce a 2- to 3-fold increase in ODC activity by placing murine L929 cells in a Crawford chamber and exposing them to 915 MHz 80% amplitude modulated microwaves at an SAR of 3.0 mW/g for 8 h. If a similar continuous wave microwave field was applied no increase in ODC activity was noted. We were unable to detect any change in the ODC activity at 2 and 4 h of exposure but were able to detect a 30 to 40% increase at 6 h. ODC activity was assayed by measuring the amount of radioactive carbon dioxide released by the enzyme from a radioactive ornithine molecule. At the time we were able to achieve a 24-fold increase in ODC activity with serum stimulation and a 22-fold increase with the phorbol ester. The same amplitude modulated or continuous wave microwave fields did not affect the growth rate or viability of either the L929 cells or human HL-60 cells. (Supported by grant # DAMD 17-89-C-6260 from the Department of Defense)

P-37 **ANALYSIS OF GENOTOXIC EFFECTS OF ELF PULSED MAGNETIC FIELDS ON HUMAN LYMPHOCYTE CULTURES BY MEANS OF CYTOKINESIS-BLOCK MICRONUCLEUS METHOD.** M.R. Scarfi, F. Bersani*, A. Cossarizza+, D. Monti+, G. Franceschetti, and C. Franceschi+. CNR-IRECE, Naples; *Dept. Physics, Univ. of Bologna; +Inst. Gen. Pathology, Univ. of Modena, Italy.

The aim of the present work was to assess the possible genotoxic effect of a pulsed magnetic field in the ELF range on human lymphocytes cultured in vitro and stimulated with phytohemagglutinin (PHA). For this purpose, the micronucleus (MN) technique by cytokinesis-block method was used. This method presents some advantages when compared with other cytogenetic techniques. In particular, it is more sensitive and a large number of cells can be scored in few hours. Moreover, as far as we know, this is the first application of this method in bioelectromagnetic research.

Cell cultures were maintained in a $C0_2$ incubator and exposed for 72 hrs to a pulsed magnetic field (PMF) generated by two parallel Helmholtz coils connected to a pulse generator (IGEA, Carpi), whose characteristics where the following: triangular magnetic field signal, maximum amplitude 2.5 mT, pulse rise time 1.2 msec. and repetition frequency 50 Hz. 12 healthy subjects were tested and for each subject 3 conditions were considered: a) control cultures, b) cultures exposed to the field, c) mitomycin-C (MMC) treated cultures (as a positive control of micronuclei formation). In some of these subjects a further condition was studied in which cells were treated with MMC and exposed to PEMF, in order to determine if PEMF would interfere with the genotoxic action of MMC (either synergistically or antagonistically). In all the above described situations no statistical difference was found between control and exposed cultures, suggesting that the used field has no genotoxic effect as assessed by the MN cytokinesis-block method.

P-38 **THE EFFECT OF ULTRA SHORT WAVE IN DIFFERENT FIELD STRENGTH ON CALMODULIN OF FOREBRAIN IN RATS.** Zongqun Zhao. Dept. of Occup. Health, Beijing Medical University, Beijing 100083 China; Weimin Li, Xian Medical University, Xian 710061, China.

The effect of ultra short wave on calmodulin in forebrains of the male rats was performed in TEM cell at 100 MHz for E-polarization. In two set experiments, all 43 wistar rats were divided into two exposure groups and two control groups randomly. One of exposure groups was exposed to the field strength at 7.63mW/cm^2 compared with its control group; another was at 0.68 mW/cm^2 compared with another control one. Irradiation was performed two hours per day for 12 days. The results showed the lower level of calmodulin in the forebrains of the rats at 7.63mW/cm^2($p < 0.05$). No change was found in another exposure group at 0.68mW/cm^2. These results might be related to the thermal effect.

P-39 **CORRELATION RELATIONSHIP BETWEEN CHROMOSOME ABERRATION IN THE BONE MARROW OF MICE AND INCIDENCE OF MICRONUCLEUS CELLS INDUCED BY MICROWAVE IRRADIATIONS.** Liu Wenkui, Zhen Hexin, Li Guanchen, Li Guoqing. Shanxi Medical College, Tai Yuan, Shanxi, China 030001.

50 mice were randomly divided into 5 groups, male and female half in half. 5 mice for chromosome aberration experiment and 5 mice for micronucleus experiment each group. 3 groups were irradiated by 40,20,10 mW/cm2 microwave 40 minutes once, respectively. It was 24 hours' interval, totaling twice. One negative control group and one positive control group were set. The negative control group was not irradiated. The positive control group was irradiated by 150 R r-ray. All mice were batchly sacrificed to be observed after the second irradiation. The results showed

it was statistically high significant in 40 mW/cm2 group and the negative control group. For the rate of micronucleus cells, the three microwave groups were higher than the negative control group. A certain field intensity of microwave can cause the increment of chromosome aberration of bone marrow of mice and incidence of micronucleus cells. The incidence of chromosome aberration and the incidence of micronucleus cells induced by microwave irradiation increased with the dose of microwave. The rate of cellar aberration and the rate of micronucleus cells have high correlation ($r=0.9867$, $p<0.01$). The rate of chromosome aberration and the rate of micronucleus cells have positive correlation ($r=0.9566$, $p<0.05$). It has been rarely reported.

P-40 **EFFECTS OF 60 Hz CYCLIC MAGNETIC FIELD EXPOSURES ON ANTIBIOTIC SENSITIVITIES OF PATHOGENIC GRAM POSITIVE AND NEGATIVE BACTERIA.** Wendell D.Winters and Xin-Hua Song*. Department of Microbiology, The University of Texas Health Science Center San Antonio, TX 78284.

Exposures to various types of time varying electromagnetic fields have been reported to cause modifications in the growth and biological response of some bacterial species. The possibility that exposures to 60 Hz cyclic magnetic fields (MF) under conditions known to induce biological changes in cultured cells could induce biological changes in both gram negative and gram positive bacteria prompted us to study the effects of MF with endpoints of effects on growth and on antibiotic sensitivities of the selected test bacteria. Our present study used time course and dose response approaches to detect effects of uniform 60 Hz cyclic MF of 3 intensities on antibiotic sensitivity (AS) responses of 3 gram positive bacterial species, i.e., Streptococcus faecalis, penicillin-sensitive (PS) and -resistant (PR) Staphylococcus aureus and of 4 gram negative species, i.e., Pseudomonas aeruginosa, Proteus mirabilis, Klebsiella pneumoniae and E. coli. Responses of AS were measured by the standard agar disk diffusion method and Mueller Hinton media in accord with International Committee for Clinical Laboratory Standards 1989 guidelines. Overall results of our studies of exposure of each of 7 bacterial species to MF of 25, 50 or 100 μT for up to 3 hrs indicated that the AS of each of the gram positive and gram negative bacteria tested could be significantly altered by MF exposure to at least one set of experimental exposure conditions. Further investigations revealed that the age and status of the antibiotic and the MF exposure intensity-time combination are major factors in detecting alterations in AS responses of MF exposed bacteria.

P-41 **EFFECTS OF A 50-Hz MAGNETIC FIELD ON THE ELECTRICAL PROPERTIES OF CHICK EMBRYO MYOLOBLASTS IN VITRO.** A. Bonincontro[1], C. Cametti[1], M. Grandolfo[2], P.L. Indovina[3], M.T. Santini[2], and P. Vecchia[2]. [1] University of Rome "La Sapienza", and GNSM, Rome, Italy; [2] National Institute of Health, and INFN - Sezione Sanita, Rome, Italy; [3] University of Naples, and INFN - Sezione Sanita, Rome, Italy.

Primary chick embryo myoblasts can be a useful tool for studying the developmental events which accompany myoblast differentiation, particularly myoblast membrane fusion. In order to determine whether the electrical properties and/or fusion in these systems are affected by 50 Hz magnetic fields, cultures taken at 24 hours of development, after the aggregation stage was completed, were exposed for different lengths of time to B-field intensities ranging from 1 to 10 mT. The coil apparatus, driven by Variacs, was designed to generate the field perpendicular to the sample plate. The B-fields were monitored by small multiturn coils placed near the sample. The current produced in these coils was correlated with the B-field intensity and provided a measure of its magnitude. Temperature was kept at 37 +/- 1°C. The electrical parameters of the myoblasts, i.e., membrane conductivity, membrane permettivity, and the conductivity of the cell interior (cytosol) were determined by the analysis of conductivity dispersion data in the RF range (10 kHz - 100 MHz) obtained by means of two impedance analyzers controlled by computer. Preliminary results indicate that the time of fusion (60 h) is not affected by these fields, but that the absolute values of the two membrane electrical parameters are. In particular, a B-field intensity-dependent decrease was observed. The maximum effect resulted after a one hour exposure to a magnetic flux density of about 5 mT. The conductivity of the cytosol remains unchanged as it controls. These data seem to indicate that exposure to 50-Hz magnetic fields affects static and dynamic membrane properties.

MECHANISMS OF ACTION

P-42 **A RATIONAL VIEW OF FREQUENCIES LIMITS FROM ULF TO IONIZING RADIATIONS.** Victor M. Fellus. 19 rue du Dr. Arnaudet, Meudon, France, 92190.

As a long time disciple of the school of d'Arsonval and the last living collaborator of d'Arsonval's assistant, I have been studying the effects of electromagnetic energy on living systems and, I would like to draw the lights to some recent rational researches confirming our previous thesis. Considering controversies about the danger or usefulness of electromagnetic energies, it is clear that they are all originated from atomic explosion on the sun, and that the full range of frequencies

reach the high atmosphere gas layers of our globe. But only a few of these frequencies reach earth being filtered through the said gas layers leaving only two openings or "windows" in the atmosphere. Through window 1 pass soft ultraviolet rays and visible light: the origin of photosynthesis and living systems. Next to the window 1 is existing a limited opening for high caloric infra red rays being the origin of warm blooded animals. Through window 2 passes all the frequencies ranging from 0.8 to 1000 Megaherz being the entire range of polarizing rays necessary for metabolic stimulation. This explains why during evolution, living systems used frequencies reaching earth for many essential processes and that they developed defenses against excessive exposures. But living systems are unable to use frequencies they were not naturally accustomed before, and, they do not have the capacity to defend themselves against artificially produced energy at these frequencies. From the work of Aachen University (FDA) we show a table of precise limits of useful and dangerous frequencies from ULF to ionizing radiations.

P-43 **A NEW APPROACH TO CANCER WITH JACOBSON RESONANCE.** Jerry I. Jacobson. Chairman of the Foundation for Alzheimers' Disease and Related Disorders, 153 Raintree Trail, Jupiter, FL 33458.

The primary objective of the study was to analyze how an oncogene might be electromagnetically induced into an altered structural state wherein a homologous normal gene would be the product, since an oncogene is a slightly altered version of a normal gene. Furthermore, molecular recrystallization and translocation of quantum genetic characters had to be achieved through the use of a mathematical apparatus by which it could be determined what the appropriate amplitude, frequency and wave form of the applied EM signal ought to be. It is denoted that the expression $mc^2 = Bvl$ coulomb resulted from an exhaustive study of the quantum phenomena as they might be linked to biological systems. Quantum phenomena discussed are the piezoelectric effect, cyclotron resonance effect, the integral and fractional quantum Hall effects and the fundamental notion of magnetic resonance. Indeed, the unification of oncogene gravitational potential and electromagnetic interaction energies are achieved by equating mc^2, the Einsteinian expression for pure energy, and Bvl coulomb, Faraday's expression for pure energy. Masses of oncogenes have been correlated with physiologic magnetic fields at about 10^8gauss.

P-44 **ION VIBRATIONAL PRECESSION: A MODEL FOR RESONANT BIOLOGICAL INTERACTIONS WITH ELF FIELDS.** J.C. Male and D.T. Edmonds*. National Grid Research and Development Centre, Leatherhead, Surrey, UK and The Clarendon Laboratory, Oxford, UK.

We propose a simple model for the observed resonant responses of certain biological systems to ELF magnetic fields. Consider an ion bound by a central force (such as may characterize a molecular binding site) and vibrating about that site under the influence of thermal excitation. When a static magnetic field is applied,

the axis of vibration will precess about the field direction at the Larmor frequency, qB/2m, where q is the ionic charge, m its mass and B the magnetic field. The vibration axis returns to a given position twice each revolution, i.e. at the cyclotron frequency, qB/m. Modulation of the magnetic field at the cyclotron frequency or its harmonics will result in synchronous modulation of the precessional torque, with possible bunching of the vibration direction at particular orientations relative to the binding site. This could influence the effectiveness of binding to the site and hence the probability of thermally activated release of the ion. A major defect of models based directly upon cyclotron resonance is that the effect may be observed only if the mean time between collisions is longer than, or at least comparable with, the cyclotron circulation period. In contrast, Larmor precession will be observed provided only that the collision time is comparable with the period of vibration under the central force. The central reason for the difference is that with cyclotron resonance both the static orbit and its modulation are determined by the extremely weak magnetic Lorentz force, whereas, in vibrational precession, the vibrational orbit is determined by the relatively strong central binding force and only the slow precessional perturbation of the motion owes its origin to the weak magnetic force.

REPRODUCTION & DEVELOPMENT

P-45 **RESPONSE OF EARLY CHICK EMBRYO TO A SINUSOIDALLY VARYING, 50 Hz MAGNETIC FIELD.** A. Ubeda*, M.A. Martinez*, M.A. Trillo, L. Chacon* and J. Leal. Dept. Investigacion, Hospital Ramon y Cajal, Carretera de Colmenar, Km. 9, Madrid 28034, Spain.

In the present study early chick embryos were exposed in vivo to a sinusoidally varying magnetic field with a 50 Hz frequency and 200 uTesla rms magnetic flux density. The conditions of incubation and field exposure were equivalent to those in previous studies on embryological effects of pulsed magnetic fields. Twenty experiments were performed. Twenty fertile eggs (10 field-exposed and 10 sham-exposed) were used in each experiment. The morphology of the embryos was described at the end of a 48 hour period of field-exposure and/or incubation. A total of 192 field-exposed embryos were compared to 191 sham-exposed organisms. The exposed sample showed a threefold increase in the proportion of morphological abnormalities (15.1%) when compared to the controls (4.7%; p=0.003; chi-square-test). These abnormalities consisted of malformed heart and/or truncal structures (neural tube and somites). The field exposure did not change the developmental mean stage reached by the normal and not-normal embryos. These results show that a 50 Hz, sinusoidal magnetic field, at 200 uTesla rms, can provoke developmental abnormalities on early chicken embryos. Similar effects were reported to be caused by pulsed magnetic fields at 100 Hz frequency and 1.0 uTesla peak-to-peak flux density. Experiments testing possible embryological effects of 50 Hz, sinusoidally varying magnetic fields, at amplitudes lower than 200 uTesla rms, are in progress.

LATE SUBMISSIONS

P-46 **EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELD EFFECTS ON SHORT TERM MEMORY.** Mark A. Wilson. Desert Hills School, Kennewick, WA 99336.

Under the influence of 60 Hz magnetic fields that meet the requirements for ion cyclotronic resonance, short term memory may be affected. This effect would be due to changes in the normal motion of calcium ions in the brain. To test this hypotheses, I built an eight arm radial maze. In order to run the maze as fast as possible, the rat needs good short term memory. By putting the maze in the middle of three coils operating at 60 Hz, and attaching a center arena D. C. magnetic coil, I was able to set up the needed components for ion cyclotron resonance. I then trained four rats to retrieve sucrose (sugar) pellets from a cup at the end of each arm. After "tuning" the fields for calcium (Ca++), I tested each rat with and without fields. Each animal was its own control. After the first set of trials was finished, with the fields not in resonance conditions, there was no significant difference between the number of errors with fields on compared to off. After "tuning" for Ca++, the ratio of the numbers of errors with field on as compared to off was 3:1. For all my experiments the grand total of possible correct choices was 312, and the total number of errors was 64. Of those errors, 51 were with the field on, whereas the total number of errors with the field off was only 13. Under conditions of my experiment, it appeared that short term memory could be affected by 60 Hz magnetic fields.

P-47 **PHASES OF BEHAVIORAL RESPONSES TO MICROWAVE MONOEXPOSURES.** Mikhail A. Navakatikyan. Republican Scientific Hygienic Center, Kiev-94, USSR 252660.

Inhibition of locomotor activity by the end of exposure and activity increase in post-exposure 1-5 months were discovered earlier at long period exposures of rats to CW generation microwaves (2375 MHz; 0.01 - 0.5 mW/cm^2;7 hours per day; for 1 - 3 months). The postponed activation of rat locomotor activity was revealed in 2 doubled experiments after monoexposure to continuous microwaves (2450 MHz; 1 mW/cm^2; 7 hours) 4 days after exposure, no changes in post-exposure 24 hours. It was attempted to repeat the latest effect evaluating defensive behavioral reflex in a shuttle-box. The effect was forestimulated in 3 exposures and evaluated, initial parameters value taken into account. White Fisher-344 line male rats aged 3 - 5 months were exposed to microwaves CW (2450 MHz; 1 mW/cm^2; 0.27 mWpg). Behavior activation was detected right after half an hour, inhibition detected after 6 hour exposure. 24 hours after 7 hour exposure no reflex changes were detected, postponed activation revealed in 4 days.

P-48 **8-mm WAVE LOW-INTENSIVE ELECTROMAGNETIC FIELDS' EFFECT ON SOME METABOLIC PROCESSES.** Yuri D. Dumansky, and Lyudmila A. Tomashevskaya. Republican Scientific Hygienic Center, 50 Popudrenko St., Kiev-94, USSR 252660.

In the experiment on animals the exposure model was created adequate to real 8-mm wave EMF effect with discontinuity time characteristics and power density levels. The experiment was conducted on 160 white rats gropped corresponding to PD levels of 140, 100 and 60 uW/cm^2. The intact group of animals kept in identical temperature-humidity and feeding conditions was chosen for control. The animals were exposed for 4 months, 12 hours daily. The dinamics of some metabolic processes in organisms of animals under study was followed by indices of urea and precipitated nitrogen contents in blood serum, glicogen contents in liver, cholinestherase activity in blood, metalloenzymes-ceruloplasmine and transferrine in blood serum, succinatedehydrogenase and cytochromeoxidase in mitochondria of rats' liver and brain. The results obtained showed that changes in protein and carbohydrate metabolism occurred reflecting an increase of urea and precipitated nitrogen contents in blood serum and glicogen decrease in rat liver, and disorders in some pherment systems. These changes were in direct dependance on actual PD level and the time of exposure to EMF. The analysis of the resulted changes in "time - effect" aspects suggests cumulative character -the degree of bioeffect expression was higher with exposure time increase.

P-49 **FUNCTIONAL STATE OF ORGANISM UNDER COMPOSED EFFECT OF EHP-ENERGY, WIDE SPECTRUM NOISE AND TEMPERATURE.** Vladimir N. Soldatchenkov, and Sergey V. Bitkin. Republican Scientific Hygienic Center, Kiev-94, USSR 252660.

Aviation transport creates possibilities for intensivity significant effect of noise and electromagnetic irradiation on the population living in sites close to civil aviation facilities. Airports located in different climatic and geographic areas of the country, it is necessary to take environmental temperature into account in the given combination. To evaluate body functional state affected by these factors the experiments were conducted on white unbred rats (females weighted]20-]40 g) according to the following scheme. The animals were exposed to EHF 3000 MHz pulsating irradiation (400 Hz 40 msec each 20 sec), levels 2500,500 and 100 uW/cm^2 12 hours daily for 2 months in unechoid thermostable chambers. At each exposure series (total 9) noise and temperature conditions of the chamber environment varied. Wide-spectrum aviation noise levels were established at 65, 75 and 85 dBa. The temperature was ranging 15 to 25°C, 20°C mid point, +/-1°C. Body functional state of animals in exposed and control groups was defined by physiological, biochemical and immunological tests. It was stated that noise and temperature within given limits perform complex modifying action onto bioeffects

of EHF exposure. Mathematical expression of body responses was obtained on the basis of second power polynoms in dependance on electromagnetic, noise and temperature characteristics of the environment.

P-50 **NON-IONIZING MICROWAVE RADIATION AS AUTOIMMUNE INDUCTOR.** Mikhail G. Shandala, and Genrikh I. Vinogradov. Republican Scientific Hygienic Center 50 Popudrenko St. Kiev-94, USSR 252660.

The experiment was conducted on Vistar White male rats. At the first stage 2 groups of rats were exposed to 2375 MHz microwaves at power density (PD) 500 and 50 $\mu W/cm^2$ for 30 days, 7 hours daily. At the end of exposure the contents of antibodies in complement absorption reaction in blood serum was investigated as well as degranulation degree of peripheric blood basophils and the level of box-forming cells in autoimmune hemolysis. It was shown that long microwave exposures result in stimulation of autoimmune processes within exposed organisms. At the second stage the rats were sacrificed and water-salt extract of brain tissue was prepared. Intact rats were injected brain tissue intraperitonially once in 2 days, 6 times total. 3 weeks after the end of immunization it was found that brain tissue injections from unexposed animals caused no changes in indices under study compared to control. Injections from brain tissue exposed to 50 $\mu W/cm^2$PD resulted in complement consumption increase with no changes in basophil degranulation and the persentage of box-forming cells. At immunization with brain tissue exposed to 500 PD all three tests under study appeared to be positive. Therefore it is possible to transfer autoimmune status caused by microwave radiation effect. The expressiveness of the process is in dependance on exposure levels.

P-51 **BEHAVIORAL THERMOREGULATION DURING RESONANT RF EXPOSURE MAY BE CUED BY AUTONOMIC THERMOREGULATORY RESPONSES.** Eleanor R. Adair and Barbara W. Adams*. John B. Pierce Foundation Laboratory, New Haven, CT 06519.

Exposure of endothermic organisms to radio frequency (RF) fields at resonance ($h=0.4\lambda$, where h=longest body dimension) produces maximal energy absorption by tissues deep in the body. At thermalizing levels, preferential heating of deep tissues may occur, yielding poor stimulation of peripheral thermosensors, inefficient behavioral thermoregulation and hyperthermia. We hypothesized that peripherally-manifested heat loss responses (vasodilation and sweating) triggered by resonant RF exposure, could augment peripheral sensation and aid cueing of behavioral responses. Four adult, male squirrel monkeys; Saimiri sciureus), equilibrated to a thermoneutral T_a of 34°C, were exposed for 10-min periods to 450 MHz CW RF fields at power densities (PD) from 2 to 8 mW/cm [SAR=0.65 (W/kg)/(mW/cm^2)]. In the absence of changes in metabolic heat production, thresholds for foot vasodilation and/or foot sweating occurred in all animals at PD=4 mW/cm^2 and above. These thresholds were similar to PDs that had stimulated selection of a

cooler environment by other monkeys, trained to thermoregulate behaviorally, in the presence of the same RF fields. Regulated deep body temperature (colonic) was similar in both cases. This strong correlation indicates involvement of autonomic responses as auxiliary cues to behavior when peripheral thermosensors are inefficiently stimulated by deeply-penetrating RF fields. (Supported by USAF Contract F33615-87-C-0607).

P-52 **SPONTANEOUS ELECTRICAL ACTIVITY OF RAT CORTEX DURING MICROWAVE EXPOSURE.** Michael I. Rudnev, Vyacheslav V. Varetsky, Lyudmila N. Galich, and Vladimir N. Djachenko. National Research Center of Radiation Medicine, AMS USSR, Melnikov Str. 53, Kiev-50, 252050, USSR.

Animals were exposed to 2450 MHz CW in anechoic chambers. SAR, estimated calorimetrically on rats cadavers aligned along E-field, was 0.27 mW/g scaled to 1 mW/cm^2 incident power. Ambient temperature in chambers was maintained at 21 +/- 2°C. EEG was recorded with glass electrodes filled with agar gel prepared on physiological saline. Liquid leads were used in exposure areas. EEG was recorded 30 min after leads connection (background), just after exposure beginning, each hour of exposure and after exposure termination for 2 min epoch at each point. Three series of experiments were conducted. In the first one animals were exposed to 10.0 and 0 mW/cm^2. In the second series three groups were used: 0, 0.1, and 1.0 mW/cm^2. Power densities of 35 and 0 mW/cm^2 were studied in the third series. Among exposed groups only 0.1 mW/cm^2 group failed to show statistically significant differences during 7 hours of exposure both in total EEG and its rhythms as compared to the sham exposed group. At the other levels CNS response to microwave exposure did not involve the whole EEG spectrum but shifted from one frequency band to another depending on exposure level and duration. This suggests that dynamic changes take place in CNS functional state during microwave exposure. Dose dependence was complicated. It was reflected by the number of affected indices, by duration of exposure after which changes were manifested, and by their temporal stability.

P-53 **RESPIRATION SYSTEM FUNCTIONAL STATE UNDER MICROWAVE EXPOSURE.** Michael I. Rudnev, Valeriy N. Degtyar. National Research Center of Radiation Medicine, AMS USSR, Melnikov Str. 53, Kiev-50, 252050, USSR.

Animals (randomly bred male rats, 180-230 g) were exposed to 2375 MHz CW in anechoic chambers for 10 days (3 h per day) at power densities (PD) of 0.03, 0.05, and 0.5 mW/cm^2. Indices of external respiration, gas metabolism, oxygen tension in muscle tissue, respiration and phosphorilation of liver, and brain mitochondria were measured after exposure termination. Significant activation of external respiration and phosphorilating respiration (state 3) of liver and brain mitochondria were found at PD of 0.03 and 0.05 mW/cm^2. This testify for activation of

compensatory mechanisms of adaptation under this exposure conditions. At PD of 0.50 mW/cm² the tendency to external respiration inhibition and uncoupling of oxidation and phosphorilation was observed.

P-54 **MICROWAVE EXPOSURE EFFECTS UPON RATS EMBRYONAL DEVELOPMENT.** Michael I. Rudnev, Anna M. Shemetun, Sergey S. Dibsky, and Galina I. Leonskaya. National Research Center of Radiation Medicine, AMS USSR, Melnikov Str. 53, Kiev-50, 252050, USSR.

Sensitive to microwave exposure (Power Density of 10 mW/cm²) day of pregnancy was determined. 19 groups were used in the experiment. Each day of pregnancy one of these groups was exposed to microwaves for seven hours. The experiment was repeated twice with adult randomly bred rats and Fisher-344 rats of 180 to 200 g. Altogether 397 animals were used. Microwave effects upon embryonal development was studied on 20 day old embryos. Pre-, postnatal, general embryonal mortality, skeleton and inner organs state were assessed. The first day of pregnancy was shown to be the most sensitive to microwave exposure at power density of 10 mW/cm² for seven hours stage of rats embryonal development.

P-55 **MODULATION OF BRAIN WAVE COHERENCE FROM A DISTANCE - SEARCH FOR AN ELECTROMAGNETIC MECHANISM.** Kurt W. Kleinschnitz, Frederick T. Travis and Kai J. Druhl. Maharishi International University, Fairfield, IA 52556.

More than 40 scientific studies have shown that groups of individuals practicing the TM-Sidhi program, a systematic mental technology developed by Maharishi Mahesh Yogi, can influence the behavior and physiology of other individuals over large distances. While the phenomenon, generally known as the "Maharishi Effect", has been demonstrated extensively, little is known about the underlying physical mechanisms. The distances involved and the known sensitivities of human senses rule out any known mechanism other than electromagnetic signals. In a recent study, Travis et al measured EEG coherence in individual subjects (TS) performing standardized tasks, and in a subject practicing the TM-Sidhi program (YF) at the same site in a different room. Using standard computerized time series analysis with objective model selection criteria (transfer function fitting), they found that changes in coherence in the YF consistently led changes in coherence in the TS with a time lag of 0 to 4 intervalls of 10 sec. accounting for 10% of the variance. This study did not control for the propagation of electromagnetic signals. Our new experimental design places the TS into an electromagnetically shielded screen room with over -40db attenuation above 10 kHz and uses a SQUID to monitor radiation at lower frequencies. EEG signals from standard locations of the 10 - 20 system are preamplified and transmitted outside the screen room by a fiber optic link. EEG coherence data are evaluated by time series analysis. At the time of submission of this abstract, experimental data were not yet available, and the new design is presented here for the sake of discussion.

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